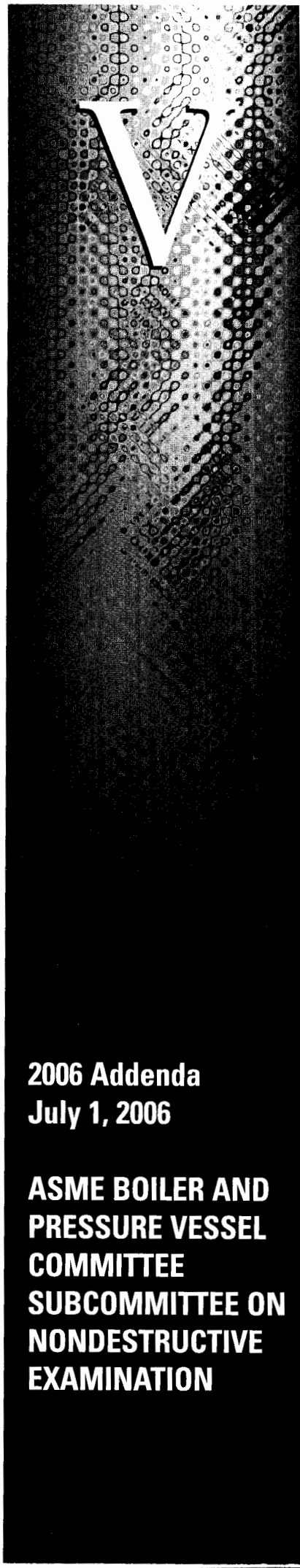
ASME BOILER AND PRESSURE VESSEL CODE
AN INTERNATIONAL CODE

NONDESTRUCTIVE EXAMINATION



2006 Addenda
July 1, 2006

ASME BOILER AND PRESSURE VESSEL COMMITTEE SUBCOMMITTEE ON NONDESTRUCTIVE EXAMINATION

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
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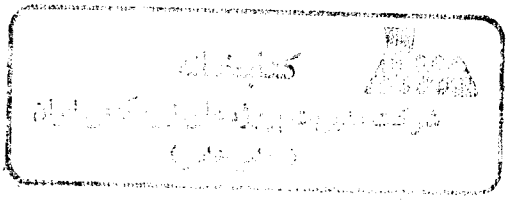

2004 ASME
BOILER AND PRESSURE VESSEL CODE

04

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ADDENDA

Colored-sheet Addenda, which include additions and revisions to individual Sections of the Code, are published annually and will be sent automatically to purchasers of the applicable Sections up to the publication of the 2007 Code. The 2004 Code is available only in the loose-leaf format; accordingly, the Addenda will be issued in the loose-leaf, replacement-page format.

INTERPRETATIONS

ASME issues written replies to inquiries concerning interpretation of technical aspects of the Code. The Interpretations for each individual Section will be published separately and will be included as part of the update service to that Section. They will be issued semiannually (July and December) up to the publication of the 2004 Code. Interpretations of Section III, Divisions 1 and 2, will be included with the update service to Subsection NCA.

Beginning with the 2004 Edition, Interpretations of the Code will be distributed annually in July with the issuance of the edition and subsequent addenda. Interpretations previously distributed in January will be posted in January at www.cstools.asme.org/interpretations and included in the July distribution.

CODE CASES

The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 2004 Code Cases book: (1) Boilers and Pressure Vessels and (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 2007 Code.

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FOREWORD

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A06

The American Society of Mechanical Engineers set up a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Vessel Committee.

The Committee's function is to establish rules of safety, relating only to pressure integrity, governing the construction[1] of boilers, pressure vessels, transport tanks and nuclear components, and inservice inspection for pressure integrity of nuclear components and transport tanks, and to interpret these rules when questions arise regarding their intent. This code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks and nuclear components, and the inservice inspection of nuclear components and transport tanks. The user of the Code should refer to other pertinent codes, standards, laws, regulations, or other relevant documents. With few exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. Recognizing this, the Committee has approved a wide variety of construction rules in this Section to allow the user or his designee to select those which will provide a pressure vessel having a margin for deterioration in service so as to give a reasonably long, safe period of usefulness. Accordingly, it is not intended that this Section be used as a design handbook; rather, engineering judgment must be employed in the selection of those sets of Code rules suitable to any specific service or need.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities. The Code does not address all aspects of these activities and those aspects which are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable designers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are responsible for the application of these programs to their design.

The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer.

The Boiler and Pressure Vessel Committee deals with the care and inspection of boilers and pressure vessels in service only to the extent of providing suggested rules of good practice as an aid to owners and their inspectors.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Boiler and Pressure Vessel Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Boiler and Pressure Vessel Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Mandatory Appendix covering preparation of technical inquiries). Proposed revisions to the Code resulting from inquiries

[1] *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

will be presented to the Main Committee for appropriate action. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by ASME.

Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute and published at *http://cstools.asme.org/wbpms/public/index.cfm?PublicReview=Revisions* to invite comments from all interested persons. After the allotted time for public review and final approval by ASME, revisions are published annually in Addenda to the Code.

Code Cases may be used in the construction of components to be stamped with the ASME Code symbol beginning with the date of their approval by ASME.

After Code revisions are approved by ASME, they may be used beginning with the date of issuance shown on the Addenda. Revisions, except for revisions to material specifications in Section II, Parts A and B, become mandatory six months after such date of issuance, except for boilers or pressure vessels contracted for prior to the end of the six-month period. Revisions to material specifications are originated by the American Society for Testing and Materials (ASTM) and other recognized national or international organizations, and are usually adopted by ASME. However, those revisions may or may not have any effect on the suitability of material, produced to earlier editions of specifications, for use in ASME construction. ASME material specifications approved for use in each construction Code are listed in the Guidelines for Acceptable ASTM Editions in Section II, Parts A and B. These Guidelines list, for each specification, the latest edition adopted by ASME, and earlier and later editions considered by ASME to be identical for ASME construction.

The Boiler and Pressure Vessel Committee in the formulation of its rules and in the establishment of maximum design and operating pressures considers materials, construction, methods of fabrication, inspection, and safety devices.

The Code Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The Scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the ASME Boiler and Pressure Vessel Committee. ASME is to be notified should questions arise concerning improper use of an ASME Code symbol.

The specifications for materials given in Section II are identical with or similar to those of specifications published by ASTM, AWS, and other recognized national or international organizations. When reference is made in an ASME material specification to a non-ASME specification for which a companion ASME specification exists, the reference shall be interpreted as applying to the ASME material specification. Not all materials included in the material specifications in Section II have been adopted for Code use. Usage is limited to those materials and grades adopted by at least one of the other Sections of the Code for application under rules of that Section. All materials allowed by these various Sections and used for construction within the scope of their rules shall be furnished in accordance with material specifications contained in Section II or referenced in the Guidelines for Acceptable ASTM Editions in Section II, Parts A and B, except where otherwise provided in Code Cases or in the applicable Section of the Code. Materials covered by these specifications are acceptable for use in items covered by the Code Sections only to the degree indicated in the applicable Section. Materials for Code use should preferably be ordered, produced, and documented on this basis; Guideline for Acceptable ASTM Editions in Section II, Part A and Guideline for Acceptable ASTM Editions in Section II, Part B list editions of ASME and year dates of specifications that meet ASME requirements and which may be used in Code construction. Material produced to an acceptable specification with requirements different from the requirements of the corresponding specifications listed in the Guideline for Acceptable ASTM Editions in Part A or Part B may also be used in accordance with the above, provided the material manufacturer or vessel manufacturer certifies with evidence acceptable to the Authorized Inspector that the corresponding requirements of specifications listed in the Guideline for Acceptable ASTM Editions in Part A or Part B have been met. Material produced to an acceptable material specification is not limited as to country of origin.

When required by context in this Section, the singular shall be interpreted as the plural, and vice-versa; and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

STATEMENT OF POLICY ON THE USE OF CODE SYMBOLS AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use Code Symbols for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Code Symbols for the benefit of the users, the enforcement jurisdictions, and the holders of the symbols who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the symbols, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding a Code Symbol and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code."

The ASME Symbol shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of a Code Symbol who may also use the facsimile in advertising to show that clearly specified items will carry the symbol. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

The ASME logo, which is the cloverleaf with the letters ASME within, shall not be used by any organization other than ASME.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Code Symbol Stamp described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the various Code Symbols shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

A05
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As of December 31, 2003

E-7 ON NONDESTRUCTIVE TESTING

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SUMMARY OF CHANGES

The 2004 Edition of this Code contains revisions in addition to the 2001 Edition with 2002 and 2003 Addenda. The revisions are identified with the designation **04** in the margin and, as described in the Foreword, become mandatory six months after the publication date of the 2004 Edition. To invoke these revisions before their mandatory date, use the designation "2004 Edition" in documentation required by this Code. If you choose not to invoke these revisions before their mandatory date, use the designation "2001 Edition through the 2003 Addenda" in documentation required by this Code.

Changes given below are identified on the pages by a margin note, **04**, placed next to the affected area.

Page	*Location*	*Change*
iii	List of Sections	Updated to reflect 04
xv	Foreword	Editorially revised
xxxi	Officers of ASTM Committee	Updated to reflect 04
1, 2	T-120	Subparagraph (j) added
7	T-221.1	Subparagraphs (c), (d), and (e) revised
8, 9	Table T-233.2	Second metric entry in Set A corrected by errata
	T-262.1(a)	Eighth line corrected by errata
	T-262.3	Subparagraph (a) revised
10	T-274	Revised in its entirety
13, 14	T-277.2	(1) New (7) added to subparagraph (a) (2) Subsequent subparagraphs renumbered accordingly
15	T-283.2	Revised in its entirety
	T-285	(1) Old T-285 deleted (2) Old T-286 redesignated as new T-285
	T-291	Subparagraphs (a), (e), (g), and (h) revised
17	I-274.1	Revised
	I-247.3	Added
34–37	Appendix A	(1) Title revised (2) A-210 revised
	Fig. A-210-1	Revised
	Fig. A-210-2	Revised
46–48	T-420	Revised in its entirety
	Table T-421	(1) Redesignated from Table T-422 (2) Essential and Nonessential variables re-ordered
	T-431	Revsied

Page	*Location*	*Change*
	T-434.2.2	Revised
	T-434.2.3	Revised
49–53	Fig. T-434.2.1	(1) Revised (2) General Notes (d), (e), and (f) added
	Fig. T-434.3	General Notes (d) and (e) added
	T-450	Added
	T-463.1.2	Revised
	T-463.1.3	Revised
	T-463.1.4	Revised
55, 56	T-464.1.4	Revised
	T-471.1	Revised
	T-471.4.1	(1) Revised (2) New Footnote 3 added (3) Subsequent footnotes renumbered accordingly
	T-472.1.1	Revised
	T-472.1.3	Revised
60–64	B-410	Figure references updated
	B-460	Revised in its entirety
	Fig. B-461.1	Redesignated from Fig. B-462
	Fig. B-461.2	Added
	Fig. B-461.3	Added
	Fig. B-462.1	Redesignated from B-463 and title revised
	Fig. B-462.3	Added
66	C-461	Title and footnote reference revised
85	T-510	Revised
95	T-641	Revised
99	T-692	Subparagraph (c) corrected by errata
101	II-642	Title revised
113	T-779	Added
139–141	Mandatory Appendix V	Added to Article 8
142	T-921.2	Revised
	Table T-921	Revised in its entirety
145	T-1021.2	Corrected by errata
573	Mandatory Appendix II	Added
574–577	Nonmandatory Appendix A	Added

NOTE:
Volume 54 of the Interpretations to Section V of the ASME Boiler and Pressure Vessel Code follows the last page of this Edition.

SUBSECTION A
NONDESTRUCTIVE METHODS OF EXAMINATION

ARTICLE 1
GENERAL REQUIREMENTS

T-110 SCOPE

(a) This Section of the Code contains requirements and methods for nondestructive examination (NDE), which are Code requirements to the extent they are specifically referenced and required by other Code Sections or referencing document. These NDE methods are intended to detect surface and internal imperfections in materials, welds, fabricated parts, and components. They include radiographic examination, ultrasonic examination, liquid penetrant examination, magnetic particle examination, eddy current examination, visual examination, leak testing, and acoustic emission examination. See Nonmandatory Appendix A of this Article for a listing of common imperfections and damage mechanisms, and the NDE methods that are generally capable of detecting them.

(b) For general terms such as *Inspection, Flaw, Discontinuity, Evaluation*, etc., refer to Mandatory Appendix I.

04 T-120 GENERAL

(a) Subsection A describes the methods of nondestructive examination to be used if referenced by other Code Sections or referencing documents.

(b) Subsection B lists Standards covering nondestructive examination methods which have been accepted as standards. These standards are nonmandatory unless specifically referenced in whole or in part in Subsection A or as indicated in other Code Sections or referencing document.

(c) Any reference to a paragraph of any Article in Subsection A of this Section includes all of the applicable rules in the paragraph.[1] In every case, reference to a paragraph includes all the subparagraphs and subdivisions under that paragraph.

(d) Reference to a standard contained in Subsection B is mandatory only to the extent specified.[2]

(e) For those documents that directly reference this Article for the qualification of NDE personnel, the qualification shall be in accordance with their employer's written practice which must be in accordance with one of the following documents:

(1) SNT-TC-1A,[3] Personnel Qualification and Certification in Nondestructive Testing; or

(2) ANSI/ASNT CP-189,[3] ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

[1] For example, reference to T-270 includes all the rules contained in T-271 through T-277.3.

[2] For example, T-233 requires that Image Quality Indicators be manufactured and identified in accordance with the requirements or alternatives allowed in SE-747 or SE-1025, and Appendices, as appropriate for the style of IQI to be used. These are the only parts of either SE-747 or SE-1025 that are mandatory in Article 2.

[3] SNT-TC-1A (2001 Edition), "Personnel Qualification and Certification in Nondestructive Testing;" and ANSI/ASNT CP-189 (2001 Edition), "ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel;" published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518.

(f) National or international central certification programs, such as the ASNT Central Certification Program (ACCP), may be alternatively used to fulfill the examination requirements of the documents listed in T-120(e) as specified in the employer's written practice.

(g) When the referencing Code Section does not specify qualifications or does not reference directly Article 1 of this Section, qualification may simply involve demonstration in routine manufacturing operations to show that the personnel performing the nondestructive examinations are competent to do so in accordance with the Manufacturer's established procedures.

(h) The user of this Article is responsible for the qualification and certification of NDE Personnel in accordance with the requirements of this Article. The Code User's[4] Quality Program shall stipulate how this is to be accomplished. Qualifications in accordance with a prior edition of SNT-TC-1A, or CP-189 are valid until recertification. Recertification or new certification shall be in accordance with the edition of SNT-TC-1A or CP-189 specified in Footnote 3.

(i) Limited certification of nondestructive examination personnel who do not perform all of the operations of a nondestructive method that consists of more than one operation, or who perform nondestructive examinations of limited scope, may be based on fewer hours of training and experience than recommended in SNT-TC-1A or CP-189. Any limitations or restrictions placed upon a person's certification shall be described in the written practice and on the certification.

(j) Either U.S. Customary Units or SI Units may be used for compliance with all requirements of this edition, but one system shall be used consistently throughout for all phases of construction.

(1) Either the U.S. Customary Units or SI Units that are listed in Mandatory Appendix II are identified in the text, or are identified in the nomenclature for equations shall be used consistently for all phases of construction (e.g., materials, design, fabrication, and reports). Since values in the two systems are not exact equivalents, each system shall be used independently of the other without mixing U.S. Customary Units and SI Units.

(2) When SI Units are selected, U.S. Customary values in referenced specifications that do not contain SI Units shall be converted to SI values to at least three significant figures for use in calculations and other aspects of construction.

[4] In this Code Section, "Code User" is any organization conducting nondestructive examinations to the requirements of this Section.

T-130 EQUIPMENT

It is the responsibility of the Code User to ensure that the examination equipment being used conforms to the requirements of this Code Section.

T-150 PROCEDURE

(a) The nondestructive examination methods included in this Section are applicable to most geometric configurations and materials encountered in fabrication under normal conditions. However, special configurations and materials may require modified methods and techniques, in which case the Manufacturer shall develop special procedures which are equivalent or superior to the methods and techniques described in this Code Section, and which are capable of producing interpretable examination results under the special conditions. Such special procedures may be modifications or combinations of methods described or referenced in this Code Section, and shall be proved by demonstration to be capable of detecting discontinuities under the special conditions, and such demonstrated capabilities shall be equivalent to the capabilities of the methods described in this Code Section when used under more general conditions. Depending on the quality assurance or quality control system requirements of the referencing Code Section, these special procedures shall be submitted to the Inspector for acceptance where required, and shall be adopted as part of the Manufacturer's quality control program.

(b) When an examination to the requirements of this Section of the Code is required by other Sections of the Code, it shall be the responsibility of the Manufacturer, fabricator, or installer to establish nondestructive examination procedures and personnel certification procedures conforming to the referencing Code requirements.

(c) When required by the referencing Code Section, all nondestructive examinations performed under this Code Section shall be done to a written procedure. This procedure shall be demonstrated to the satisfaction of the Inspector. The procedure or method shall comply with the applicable requirements of this Section for the particular examination method. Where so required, written procedures shall be made available to the Inspector on request. At least one copy of each procedure shall be readily available to the Manufacturer's Nondestructive Examination Personnel for their reference and use.

T-160 CALIBRATION

(a) The Manufacturer, fabricator, or installer shall assure that all equipment calibrations required by Subsection A and/or Subsection B are performed.

(b) When special procedures are developed [see T-150(a)], the Code User shall specify what calibration is necessary, when calibration is required.

T-170 EXAMINATIONS AND INSPECTIONS

(a) The Inspector concerned with the fabrication of the vessel or pressure part shall have the duty of verifying to his satisfaction that all examinations required by the referencing Code Section have been made to the requirements of this Section and the referencing document(s). He shall have the right to witness any of these examinations to the extent stated in the referencing document(s). Throughout this Section of the Code, the word *Inspector* means the *Authorized Inspector* who has been qualified as required in the various referencing Code Sections.

(b) The special distinction established in the various Code Sections between *inspection* and *examination* and the personnel performing them is also adopted in this Code Section. In other words, the term *inspection* applies to the functions performed by the *Authorized Inspector*, but the term *examination* applies to those quality control functions performed by personnel employed by the Manufacturer. One area of occasional deviation from these distinctions exists. In the ASTM Standard Methods and Recommended Practices incorporated in this Section of the Code by reference or by reproduction in Subsection B, the words *inspection* or *Inspector*, which frequently occur in the text or titles of the referenced ASTM documents, may actually describe what the Code calls *examination* or *examiner*. This situation exists because ASTM has no occasion to be concerned with the distinctions which the Code makes between *inspection* and *examination*, since ASTM activities and documents do not involve the *Authorized Inspector* described in the Code Sections. However, no attempt has been made to edit the ASTM documents to conform with Code usage; this should cause no difficulty if the users of this Section recognize that the terms *inspection, testing,* and *examination* in the ASTM documents referenced in Subsection B do not describe duties of the *Authorized Code Inspector* but rather describe the things to be done by the Manufacturer's *examination* personnel.

T-180 EVALUATION

The acceptance standards for these methods shall be as stated in the referencing document(s).

T-190 RECORDS/DOCUMENTATION

Records/Documentation shall be in accordance with the referencing document(s) and the applicable requirements of Subsection A and/or B of this Code Section. The Code User shall be responsible for all required Records/Documentation.

ARTICLE 1
MANDATORY APPENDIX

APPENDIX I — GLOSSARY OF TERMS FOR NONDESTRUCTIVE EXAMINATION

I-110 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms common to all methods used in Nondestructive Examination.

I-120 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section A provides the definition of terms listed in I-130(a).

(c) Paragraph I-130(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

I-130 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: *defect, discontinuity, evaluation, false indication, flaw, flaw characterization, imperfection, interpretation, nonrelevant indication, relevant indication.*

(b) The following Code terms are used in conjunction with this Article:

area of interest — the specific portion of the object that is to be evaluated as defined by the referencing Code Section

indication — the response or evidence from a nondestructive examination that requires interpretation to determine relevance

inspection — the observation of any operation performed on materials and/or components to determine its acceptability in accordance with given criteria

limited certification — an accreditation of an individual's qualification to perform some but not all of the operations within a given nondestructive examination method or technique that consists of one or more than one operation, or to perform nondestructive examinations within a limited scope of responsibility

method — the following is a list of nondestructive examination methods and respective abbreviations used within the scope of Section V:

RT — Radiography
UT — Ultrasonics
MT — Magnetic Particle
PT — Liquid Penetrants
VT — Visual
LT — Leak Testing
ET — Electromagnetic (Eddy Current)
AE — Acoustic Emission

nondestructive examination (NDE) — the development and application of technical methods to examine materials and/or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure, interpret, and evaluate flaws

operation — a specific phase of a method or technique

procedure — an orderly sequence of actions describing how a specific technique shall be applied

sensitivity — a measure of the level of response from a discontinuity by a nondestructive examination

technique — a technique is a specific way of utilizing a particular nondestructive examination (NDE) method

ARTICLE 1
NONMANDATORY APPENDIX

APPENDIX A — IMPERFECTION VS TYPE OF NDE METHOD

A-110 SCOPE

Table A-110 lists common imperfections and the NDE methods that are generally capable of detecting them.

Caution — Table A-110 should be regarded for general guidance only and not as a basis for requiring or prohibiting a particular type of NDE method for a specific application. For example, material and product form are factors that could result in differences from the degree of effectiveness implied in the table. For service-induced imperfections, accessibility and other conditions at the examination location are also significant factors that must be considered in selecting a particular NDE method. In addition, Table A-110 must not be considered to be all inclusive; there are several NDE methods/techniques and imperfections not listed in the table. The user must consider all applicable conditions when selecting NDE methods for a specific application.

TABLE A-110
IMPERFECTION VS TYPE OF NDE METHOD

	Surface [Note (1)]		Sub-surf. [Note (2)]		Volumetric [Note (3)]				
	VT	PT	MT	ET	RT	UTA	UTS	AE	UTT
Service-Induced Imperfections									
Abrasive Wear (Localized)	●	◑	◑		●	◑	◑		◑
Baffle Wear (Heat Exchangers)	●			◑					
Corrosion-Assisted Fatigue Cracks	○	◑	●		○	●		●	
Corrosion -Crevice	●								○
-General / Uniform				○	◑		◑		●
-Pitting	●	●	○		●	○	○	◑	○
-Selective	●	●	○						○
Creep (Primary) [Note (4)]									
Erosion	●				●	○	◑		◑
Fatigue Cracks	○	●	●	◑	◑	●		●	
Fretting (Heat Exchanger Tubing)	◑			◑					◑
Hot Cracking		◑	◑		◑	○		◑	
Hydrogen-Induced Cracking		◑	◑		○	◑		◑	
Intergranular Stress-Corrosion Cracks						○			
Stress-Corrosion Cracks (Transgranular)	○	◑	●	○	◑	◑		◑	
Welding Imperfections									
Burn Through	●				●	◑			○
Cracks	○	●	●	◑	◑	●	○	●	
Excessive/Inadequate Reinforcement	●				●	◑	○		○
Inclusions (Slag/Tungsten)			◑	◑	●	◑	○	○	
Incomplete Fusion	◑		◑	◑	◑	●	◑	◑	
Incomplete Penetration	◑	●	●	◑	●	●	◑	◑	
Misalignment	●				●	◑			
Overlap	◑	●	●	○		○			
Porosity	●	●	○		●	◑	○	○	
Root Concavity	●				●	◑	○	○	○
Undercut	●	◑	◑	○	●	◑	○	○	
Product Form Imperfections									
Bursts (Forgings)	○	●	●	◑	◑	◑	◑	●	
Cold Shuts (Castings)	○	●	●	○	●	◑	◑	○	
Cracks (All Product Forms)	○	●	●	◑	◑	◑	○	●	
Hot Tear (Castings)	○	●	●	◑	◑	◑	○	○	
Inclusions (All Product Forms)			◑	◑	●	◑	○	○	
Lamination (Plate, Pipe)	○	◑	◑			○	●	○	●
Laps (Forgings)	○	●	●	○	◑		○	○	
Porosity (Castings)	●	●	○		●	○	○	○	
Seams (Bar, Pipe)	○	●	●	◑	○	◑	◑	○	

Legend:
AE – Acoustic Emission
ET – Electromagnetic (Eddy Current)
MT – Magnetic Particle
PT – Liquid Penetrant
RT – Radiography
UTA – Ultrasonic Angle Beam
UTS – Ultrasonic Straight Beam
UTT – Ultrasonic Thickness Measurement
VT – Visual

● – All or most standard techniques will detect this imperfection under all or most conditions.
◑ – One or more standard technique(s) will detect this imperfection under certain conditions.
○ – Special techniques, conditions, and/or personnel qualifications are required to detect this imperfection.

GENERAL NOTE: Table A-110 lists imperfections and NDE methods that are capable of detecting them. It must be kept in mind that this table is very general in nature. Many factors influence the detectability of imperfections. This table assumes that only qualified personnel are performing nondestructive examinations and good conditions exist to permit examination (good access, surface conditions, cleanliness, etc.).

NOTES:
(1) Methods capable of detecting imperfections that are open to the surface only.
(2) Methods capable of detecting imperfections that are either open to the surface or slightly subsurface.
(3) Methods capable of detecting imperfections that may be located anywhere within the examined volume.
(4) Various NDE methods are capable of detecting tertiary (3rd stage) creep and some, particularly using special techniques, are capable of detecting secondary (2nd stage) creep. There are various descriptions/definitions for the stages of creep and a particular description/definition will not be applicable to all materials and product forms.

ARTICLE 2
RADIOGRAPHIC EXAMINATION

T-210 SCOPE

The radiographic method described in this Article for examination of materials including castings and welds shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are in Mandatory Appendix V of this Article.

Certain product-specific, technique-specific, and application-specific requirements are also given in other Mandatory Appendices of this Article, as listed in the table of contents. These additional requirements shall also be complied with when an Appendix is applicable to the radiographic or radioscopic examination being conducted.

T-220 GENERAL REQUIREMENTS

T-221 Procedure Requirements

04 **T-221.1 Written Procedure.** Radiographic examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(*a*) material type and thickness range

(*b*) isotope or maximum X-ray voltage used

(*c*) source-to-object distance (*D* in T-274.1)

(*d*) distance from source side of object to film (*d* in T-274.1)

(*e*) source size (*F* in T-274.1)

(*f*) film brand and designation

(*g*) screens used

A05 **T-221.2 Procedure Demonstration.** Demonstration of the density and image quality indicator (IQI) image requirements of the written procedure on production or technique radiographs shall be considered satisfactory evidence of compliance with that procedure.

T-222 Surface Preparation

T-222.1 Materials Including Castings. Surfaces shall satisfy the requirements of the applicable materials specification or referencing Code Section, with additional conditioning, if necessary, by any suitable process to such a degree that the resulting radiographic image due to any surface irregularities cannot mask or be confused with the image of any discontinuity.

T-222.2 Welds. The weld ripples or weld surface irregularities on both the inside (where accessible) and outside shall be removed by any suitable process to such a degree that the resulting radiographic image due to any surface irregularities cannot mask or be confused with the image of any discontinuity.

The finished surface of all butt-welded joints may be flush with the base material or may have reasonably uniform crowns, with reinforcement not to exceed that specified in the referencing Code Section.

T-223 Backscatter Radiation

A lead symbol "B," with minimum dimensions of $\frac{1}{2}$ in. (13 mm) in height and $\frac{1}{16}$ in. (1.5 mm) in thickness, shall be attached to the back of each film holder during each exposure to determine if backscatter radiation is exposing the film.

T-224 System of Identification

A system shall be used to produce permanent identification on the radiograph traceable to the contract, component, weld or weld seam, or part numbers, as appropriate. In addition, the Manufacturer's symbol or name and the date of the radiograph shall be plainly and permanently included on the radiograph. This identification system does not necessarily require that the information appear as radiographic images. In any case, this information shall not obscure the area of interest.

T-225 Monitoring Density Limitations of Radiographs

Either a densitometer or step wedge comparison film shall be used for judging film density.

T-226 Extent of Examination

The extent of radiographic examination shall be as specified by the referencing Code Section.

TABLE T-233.1
HOLE-TYPE IQI DESIGNATION, THICKNESS, AND HOLE DIAMETERS

IQI Designation	IQI Thickness, in. (mm)	1*T* Hole Diameter, in. (mm)	2*T* Hole Diameter, in. (mm)	4*T* Hole Diameter, in. (mm)
5	0.005 (0.13)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
7	0.0075 (0.19)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
10	0.010 (0.25)	0.010 (0.25)	0.020 (0.51)	0.040 (1.02)
12	0.0125 (0.32)	0.0125 (0.32)	0.025 (0.64)	0.050 (1.27)
15	0.015 (0.38)	0.015 (0.38)	0.030 (0.76)	0.060 (1.52)
17	0.0175 (0.44)	0.0175 (0.44)	0.035 (0.89)	0.070 (1.78)
20	0.020 (0.51)	0.020 (0.51)	0.040 (1.02)	0.080 (2.03)
25	0.025 (0.64)	0.025 (0.64)	0.050 (1.27)	0.100 (2.54)
30	0.030 (0.76)	0.030 (0.76)	0.060 (1.52)	0.120 (3.05)
35	0.035 (0.89)	0.035 (0.89)	0.070 (1.78)	0.140 (3.56)
40	0.040 (1.02)	0.040 (1.02)	0.080 (2.03)	0.160 (4.06)
45	0.045 (1.14)	0.045 (1.14)	0.090 (2.29)	0.180 (4.57)
50	0.050 (1.27)	0.050 (1.27)	0.100 (2.54)	0.200 (5.08)
60	0.060 (1.52)	0.060 (1.52)	0.120 (3.05)	0.240 (6.10)
70	0.070 (1.78)	0.070 (1.78)	0.140 (3.56)	0.280 (7.11)
80	0.080 (2.03)	0.080 (2.03)	0.160 (4.06)	0.320 (8.13)
100	0.100 (2.54)	0.100 (2.54)	0.200 (5.08)	0.400 (10.16)
120	0.120 (3.05)	0.120 (3.05)	0.240 (6.10)	0.480 (12.19)
140	0.140 (3.56)	0.140 (3.56)	0.280 (7.11)	0.560 (14.22)
160	0.160 (4.06)	0.160 (4.06)	0.320 (8.13)	0.640 (16.26)
200	0.200 (5.08)	0.200 (5.08)	0.400 (10.16)	...
240	0.240 (6.10)	0.240 (6.10)	0.480 (12.19)	...
280	0.280 (7.11)	0.280 (7.11)	0.560 (14.22)	...

T-230 EQUIPMENT AND MATERIALS

T-231 Film

T-231.1 Selection. Radiographs shall be made using industrial radiographic film.

T-231.2 Processing. Standard Guide for Controlling the Quality of Industrial Radiographic Film Processing, SE-999, or paragraphs 23 through 26 of Standard Guide for Radiographic Examination SE-94 shall be used as a guide for processing film.

T-232 Intensifying Screens

Intensifying screens may be used when performing radiographic examination in accordance with this Article.

T-233 Image Quality Indicator (IQI) Design

T-233.1 Standard IQI Design. IQIs shall be either the hole type or the wire type. Hole-type IQIs shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-1025. Wire-type IQIs shall be manufactured and identified in accordance with the requirements or alternates allowed in SE-747, except that the largest wire number or the identity number may be omitted. ASME standard IQIs shall consist of those in Table T-233.1 for hole type and those in Table T-233.2 for wire type.

TABLE T-233.2
WIRE IQI DESIGNATION, WIRE DIAMETER, AND WIRE IDENTITY

04

Set A			Set B		
Wire Diameter, in.	(mm)	Wire Identity	Wire Diameter, in.	(mm)	Wire Identity
0.0032	(0.08)	1	0.010	(0.25)	6
0.004	(0.10)	2	0.013	(0.33)	7
0.005	(0.13)	3	0.016	(0.41)	8
0.0063	(0.16)	4	0.020	(0.51)	9
0.008	(0.20)	5	0.025	(0.64)	10
0.010	(0.25)	6	0.032	(0.81)	11

Set C			Set D		
Wire Diameter, in.	(mm)	Wire Identity	Wire Diameter, in.	(mm)	Wire Identity
0.032	(0.81)	11	0.100	(2.54)	16
0.040	(1.02)	12	0.126	(3.20)	17
0.050	(1.27)	13	0.160	(4.06)	18
0.063	(1.60)	14	0.200	(5.08)	19
0.080	(2.03)	15	0.250	(6.35)	20
0.100	(2.54)	16	0.320	(8.13)	21

T-233.2 Alternative IQI Design. IQIs designed and manufactured in accordance with other national or international standards may be used provided the requirements of either (a) or (b) below, and the material requirements of T-276.1 are met.

(a) Hole Type IQIs. The calculated Equivalent IQI Sensitivity (EPS), per SE-1025, Appendix X1, is equal to or better than the required standard hole type IQI.

(b) Wire Type IQIs. The alternative wire IQI essential wire diameter is equal to or less than the required standard IQI essential wire.

A05 **T-234 Facilities for Viewing of Radiographs**

Viewing facilities shall provide subdued background lighting of an intensity that will not cause reflections, shadows, or glare on the radiograph that interfere with the interpretation process. Equipment used to view radiographs for interpretation shall provide a variable light source sufficient for the essential IQI hole or designated wire to be visible for the specified density range. The viewing conditions shall be such that light from around the outer edge of the radiograph or coming through low-density portions of the radiograph does not interfere with interpretation.

T-260 CALIBRATION

T-261 Source Size

T-261.1 Verification of Source Size. The equipment manufacturer's or supplier's publications, such as technical manuals, decay curves, or written statements documenting the actual or maximum source size or focal spot, shall be acceptable as source size verification.

T-261.2 Determination of Source Size. When manufacturer's or supplier's publications are not available, source size may be determined as follows:

(a) X-Ray Machines. For X-ray machines operating at 500 kV and less, the focal spot size may be determined by the pinhole method,[1] or in accordance with SE-1165, Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging.

(b) Iridium-192 Sources. For Iridium-192, the source size may be determined in accordance with SE-1114, Standard Test Method for Determining the Focal Size of Iridium-192 Industrial Radiographic Sources.

T-262 Densitometer and Step Wedge Comparison Film

04 **T-262.1 Densitometers.** Densitometers shall be calibrated at least every 90 days during use as follows:

(a) A national standard step tablet or a step wedge calibration film, traceable to a national standard step tablet and having at least 5 steps with neutral densities from at least 1.0 through 4.0, shall be used. The step wedge calibration film shall have been verified within the last year by comparison with a national standard step tablet unless, prior to first use, it was maintained in the original light-tight and waterproof sealed package as supplied by the manufacturer. Step wedge calibration films may be used without verification for one year upon opening, provided it is within the manufacturer's stated shelf life.

(b) The densitometer manufacturer's step-by-step instructions for the operation of the densitometer shall be followed.

(c) The density steps closest to 1.0, 2.0, 3.0, and 4.0 on the national standard step tablet or step wedge calibration film shall be read.

(d) The densitometer is acceptable if the density readings do not vary by more than ± 0.05 density units from the actual density stated on the national standard step tablet or step wedge calibration film.

T-262.2 Step Wedge Comparison Films. Step wedge comparison films shall be verified prior to first use, unless performed by the manufacturer, as follows:

(a) The density of the steps on a step wedge comparison film shall be verified by a calibrated densitometer.

(b) The step wedge comparison film is acceptable if the density readings do not vary by more than ± 0.1 density units from the density stated on the step wedge comparison film.

T-262.3 Periodic Verification 04

(a) Densitometers. Periodic cablibration verification checks shall be performed as described in T-262.1 at the beginning of each shift, after 8 hr of continuous use, or after change of apertures, whichever comes first.

(b) Step Wedge Comparison Films. Verification checks shall be performed annually per T-262.2.

T-262.4 Documentation

(a) Densitometers. Densitometer calibrations required by T-262.1 shall be documented, but the actual readings for each step do not have to be recorded. Periodic densitometer verification checks required by T-262.3(a) do not have to be documented.

(b) Step Wedge Calibration Films. Step wedge calibration film verifications required by T-262.1(a) shall be documented, but the actual readings for each step do not have to be recorded.

(c) Step Wedge Comparison Films. Step wedge comparison film verifications required by T-262.2 and T-262.3(b) shall be documented, but the actual readings for each step do not have to be recorded.

[1] Nondestructive Testing Handbook, Volume I, First Edition, pp. 14.32–14.33, "Measuring Focal-Spot Size." Also, pp. 20–21 of *Radiography in Modern Industry,* Fourth Edition.

T-270 EXAMINATION

T-271 Radiographic Technique[2]

A single-wall exposure technique shall be used for radiography whenever practical. When it is not practical to use a single-wall technique, a double-wall technique shall be used. An adequate number of exposures shall be made to demonstrate that the required coverage has been obtained.

T-271.1 Single-Wall Technique. In the single-wall technique, the radiation passes through only one wall of the weld (material), which is viewed for acceptance on the radiograph.

T-271.2 Double-Wall Technique. When it is not practical to use a single-wall technique, one of the following double-wall techniques shall be used.

(a) Single-Wall Viewing. For materials and for welds in components, a technique may be used in which the radiation passes through two walls and only the weld (material) on the film-side wall is viewed for acceptance on the radiograph. When complete coverage is required for circumferential welds (materials), a minimum of three exposures taken 120 deg. to each other shall be made.

(b) Double-Wall Viewing. For materials and for welds in components $3\frac{1}{2}$ in. (89 mm) or less in nominal outside diameter, a technique may be used in which the radiation passes through two walls and the weld (material) in both walls is viewed for acceptance on the same radiograph. For double-wall viewing, only a source-side IQI shall be used. Care should be exercised to ensure that the required geometric unsharpness is not exceeded. If the geometric unsharpness requirement cannot be met, then single-wall viewing shall be used.

(1) For welds, the radiation beam may be offset from the plane of the weld at an angle sufficient to separate the images of the source-side and film-side portions of the weld so that there is no overlap of the areas to be interpreted. When complete coverage is required, a minimum of two exposures taken 90 deg. to each other shall be made for each joint.

(2) As an alternative, the weld may be radiographed with the radiation beam positioned so that the images of both walls are superimposed. When complete coverage is required, a minimum of three exposures taken at either 60 deg. or 120 deg. to each other shall be made for each joint.

(3) Additional exposures shall be made if the required radiographic coverage cannot be obtained using the minimum number of exposures indicated in (b)(1) or (b)(2) above.

[2] Sketches showing suggested source, film, and IQI placements for pipe or tube welds are illustrated in Article 2, Nonmandatory Appendix A.

T-272 Radiation Energy

The radiation energy employed for any radiographic technique shall achieve the density and IQI image requirements of this Article.

T-273 Direction of Radiation

The direction of the central beam of radiation should be centered on the area of interest whenever practical.

T-274 Geometric Unsharpness

T-274.1 Geometric Unsharpness Determination. 04
Geometric unsharpness of the radiograph shall be determined in accordance with: A05 A06

$$U_g = Fd/D$$

where

U_g = geometric unsharpness
F = source size: the maximum projected dimension of the radiating source (or effective focal spot) in the plane perpendicular to the distance D from the weld or object being radiographed
D = distance from source of radiation to weld or object being radiographed
d = distance from source side of weld or object being radiographed to the film

D and d shall be determined at the approximate center of the area of interest.

NOTE: Alternatively, a nomograph as shown in Standard Guide for Radiographic Examination SE-94 may be used.

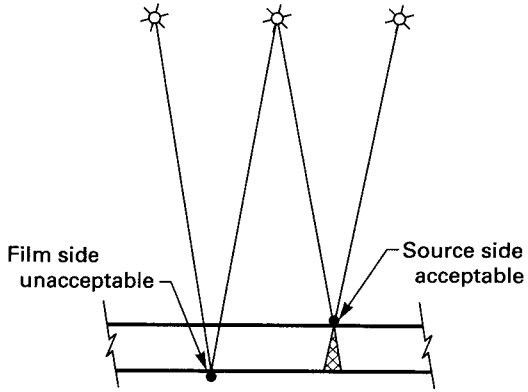
T-274.2 Geometric Unsharpness Limitations. Recommended maximum values for geometric unsharpness are as follows:

Material Thickness, in. (mm)	U_g Maximum, in. (mm)
Under 2 (50)	0.020 (0.51)
2 through 3 (50–75)	0.030 (0.76)
Over 3 through 4 (75–100)	0.040 (1.02)
Greater than 4 (100)	0.070 (1.78)

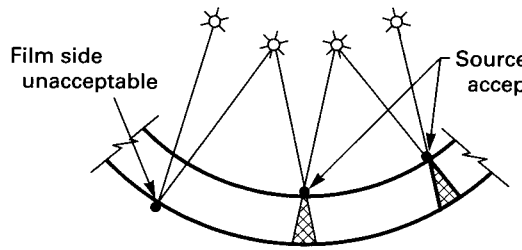
NOTE: Material thickness is the thickness on which the IQI is based.

T-275 Location Markers

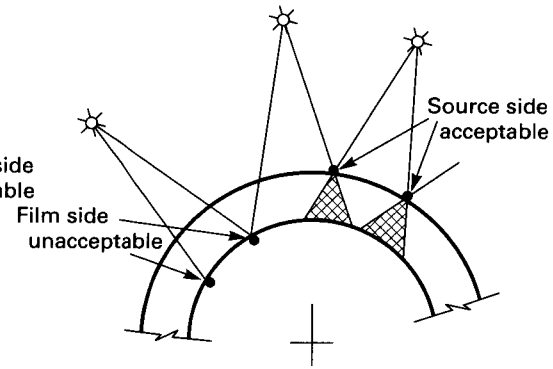
Location markers (see Fig. T-275), which are to appear as radiographic images on the film, shall be placed on the



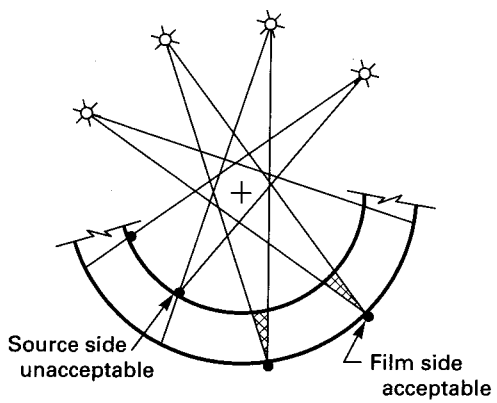
Flat component or longitudinal seam
[See T-275.1(a)(1)]
[See sketch (e) for alternate]
(a)



Curved components with radiation source to film distance less than radius of component
[See T-275.1(a)(2)]
(b)

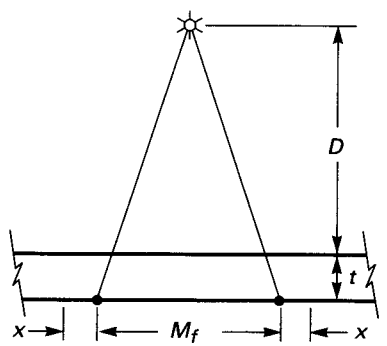


Curved components with convex surface towards radiation source
[See T-275.1(a)(3)]
(c)



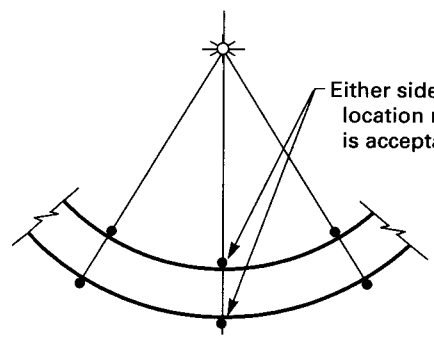
Curved components with radiation source to film distance greater than radius of curvature
[See T-275.1(b)(1)]
(d)

LEGEND: Radiation source — ☼
Location marker — ●
Component center — +



Source side marker alternate
Flat component or logitudinal seam
$x = (t / D)(M_f / 2)$

x = additional required coverage beyond film side location marker
t = component thickness
M_f = film side location marker interval
D = source to component distance
[See T-275.1(b)(2)]
(e)



Curved components with radiation source at center curvature
[See T-275.1(c)]
(f)

FIG. T-275 LOCATION MARKER SKETCHES

part, not on the exposure holder/cassette. Their locations shall be permanently marked on the surface of the part being radiographed when permitted, or on a map, in a manner permitting the area of interest on a radiograph to be accurately traceable to its location on the part, for the required retention period of the radiograph. Evidence shall also be provided on the radiograph that the required coverage of the region being examined has been obtained. Location markers shall be placed as follows.

T-275.1 Single-Wall Viewing

(a) Source-Side Markers. Location markers shall be placed on the source side when radiographing the following:

(1) flat components or longitudinal joints in cylindrical or conical components;

(2) curved or spherical components whose concave side is toward the source and when the "source-to-material" distance is less than the inside radius of the component;

(3) curved or spherical components whose convex side is toward the source.

(b) Film-Side Markers

(1) Location markers shall be placed on the film side when radiographing either curved or spherical components whose concave side is toward the source and when the "source-to-material" distance is greater than the inside radius.

(2) As an alternative to source-side placement in T-275.1(a)(1), location markers may be placed on the film side when the radiograph shows coverage beyond the location markers to the extent demonstrated by Fig. T-275, sketch (e), and when this alternate is documented in accordance with T-291.

(c) Either Side Markers. Location markers may be placed on either the source side or film side when radiographing either curved or spherical components whose concave side is toward the source and the "source-to-material" distance equals the inside radius of the component.

T-275.2 Double-Wall Viewing. For double-wall viewing, at least one location marker shall be placed adjacent to the weld (or on the material in the area of interest) for each radiograph.

T-275.3 Mapping the Placement of Location Markers. When inaccessibility or other limitations prevent the placement of markers as stipulated in T-275.1 and T-275.2, a dimensioned map of the actual marker placement shall accompany the radiographs to show that full coverage has been obtained.

T-276 IQI Selection

T-276.1 Material. IQIs shall be selected from either the same alloy material group or grade as identified in SE-1025, or SE-747, as applicable, or from an alloy material group or grade with less radiation absorption than the material being radiographed.

T-276.2 Size. The designated hole IQI or essential wire shall be as specified in Table T-276. A thinner or thicker hole-type IQI may be substituted for any section thickness listed in Table T-276, provided an equivalent IQI sensitivity is maintained. See T-283.2.

(a) Welds With Reinforcements. The thickness on which the IQI is based is the nominal single-wall thickness plus the estimated weld reinforcement not to exceed the maximum permitted by the referencing Code Section. Backing rings or strips shall not be considered as part of the thickness in IQI selection. The actual measurement of the weld reinforcement is not required.

(b) Welds Without Reinforcements. The thickness on which the IQI is based is the nominal single-wall thickness. Backing rings or strips shall not be considered as part of the weld thickness in IQI selection.

T-276.3 Welds Joining Dissimilar Materials or Welds With Dissimilar Filler Metal. When the weld metal is of an alloy group or grade that has a radiation attenuation that differs from the base material, the IQI material selection shall be based on the weld metal and be in accordance with T-276.1. When the density limits of T-282.2 cannot be met with one IQI, and the exceptional density area(s) is at the interface of the weld metal and the base metal, the material selection for the additional IQIs shall be based on the base material and be in accordance with T-276.1.

T-277 Use of IQIs to Monitor Radiographic Examination

T-277.1 Placement of IQIs

(a) Source-Side IQI(s). The IQI(s) shall be placed on the source side of the part being examined, except for the condition described in T-277.1(b).

When, due to part or weld configuration or size, it is not practical to place the IQI(s) on the part or weld, the IQI(s) may be placed on a separate block. Separate blocks shall be made of the same or radiographically similar materials (as defined in SE-1025) and may be used to facilitate IQI positioning. There is no restriction on the separate block thickness, provided the IQI/area-of-interest density tolerance requirements of T-282.2 are met.

(1) The IQI on the source side of the separate block shall be placed no closer to the film than the source side of the part being radiographed.

TABLE T-276
IQI SELECTION

Nominal Single-Wall Material Thickness Range		IQI			
		Source Side		Film Side	
in.	mm	Hole-Type Designation	Wire-Type Essential Wire	Hole-Type Designation	Wire-Type Essential Wire
Up to 0.25, incl.	Up to 6.4, incl.	12	5	10	4
Over 0.25 through 0.375	Over 6.4 through 9.5	15	6	12	5
Over 0.375 through 0.50	Over 9.5 through 12.7	17	7	15	6
Over 0.50 through 0.75	Over 12.7 through 19.0	20	8	17	7
Over 0.75 through 1.00	Over 19.0 through 25.4	25	9	20	8
Over 1.00 through 1.50	Over 25.4 through 38.1	30	10	25	9
Over 1.50 through 2.00	Over 38.1 through 50.8	35	11	30	10
Over 2.00 through 2.50	Over 50.8 through 63.5	40	12	35	11
Over 2.50 through 4.00	Over 63.5 through 101.6	50	13	40	12
Over 4.00 through 6.00	Over 101.6 through 152.4	60	14	50	13
Over 6.00 through 8.00	Over 152.4 through 203.2	80	16	60	14
Over 8.00 through 10.00	Over 203.2 through 254.0	100	17	80	16
Over 10.00 through 12.00	Over 254.0 through 304.8	120	18	100	17
Over 12.00 through 16.00	Over 304.8 through 406.4	160	20	120	18
Over 16.00 through 20.00	Over 406.4 through 508.0	200	21	160	20

(2) The separate block shall be placed as close as possible to the part being radiographed.

(3) When hole-type IQIs are used, the block dimensions shall exceed the IQI dimensions such that the outline of at least three sides of the IQI image shall be visible on the radiograph.

(b) Film-Side IQI(s). Where inaccessibility prevents hand placing the IQI(s) on the source side, the IQI(s) shall be placed on the film side in contact with the part being examined. A lead letter "F" shall be placed adjacent to or on the IQI(s), but shall not mask the essential hole where hole IQIs are used.

(c) IQI Placement for Welds — Hole IQIs. The IQI(s) may be placed adjacent to or on the weld. The identification number(s) and, when used, the lead letter "F," shall not be in the area of interest, except when geometric configuration makes it impractical.

(d) IQI Placement for Welds — Wire IQIs. The IQI(s) shall be placed on the weld so that the length of the wires is perpendicular to the length of the weld. The identification numbers and, when used, the lead letter "F," shall not be in the area of interest, except when geometric configuration makes it impractical.

(e) IQI Placement for Materials Other Than Welds. The IQI(s) with the IQI identification number(s), and, when used, the lead letter "F," may be placed in the area of interest.

04 **T-277.2 Number of IQIs.** When one or more film holders are used for an exposure, at least one IQI image shall appear on each radiograph except as outlined in (b) below.

(a) Multiple IQIs. If the requirements of T-282 are met by using more than one IQI, one shall be representative of the lightest area of interest and the other the darkest area of interest; the intervening densities on the radiograph shall be considered as having acceptable density.

(b) Special Cases[3]

(1) For cylindrical components where the source is placed on the axis of the component for a single exposure, at least three IQIs, spaced approximately 120 deg. apart, are required under the following conditions:

(a) When the complete circumference is radiographed using one or more film holders, or;

(b) When a section or sections of the circumference, where the length between the ends of the outermost sections span 240 or more deg., is radiographed using one or more film holders. Additional film locations may be required to obtain necessary IQI spacing.

(2) For cylindrical components where the source is placed on the axis of the component for a single exposure, at least three IQIs, with one placed at each end of the span of the circumference radiographed and one in the approximate center of the span, are required under the following conditions:

(a) When a section of the circumference, the length of which is greater than 120 deg. and less than 240 deg., is radiographed using just one film holder, or;

(b) When a section or sections of the circumference, where the length between the ends of the outermost

[3] Refer to Nonmandatory Appendix D for additional guidance.

sections span less than 240 deg., is radiographed using more than one film holder.

(3) In *(1)* and *(2)* above, where sections of longitudinal welds adjoining the circumferential weld are radiographed simultaneously with the circumferential weld, an additional IQI shall be placed on each longitudinal weld at the end of the section most remote from the junction with the circumferential weld being radiographed.

(4) For spherical components where the source is placed at the center of the component for a single exposure, at least three IQIs, spaced approximately 120 deg. apart, are required under the following conditions:

(a) When a complete circumference is radiographed using one or more film holders, or;

(b) When a section or sections of a circumference, where the length between the ends of the outermost sections span 240 or more deg., is radiographed using one or more film holders. Additional film locations may be required to obtain necessary IQI spacing.

(5) For spherical components where the source is placed at the center of the component for a single exposure, at least three IQIs, with one placed at each end of the radiographed span of the circumference radiographed and one in the approximate center of the span, are required under the following conditions:

(a) When a section of a circumference, the length of which is greater than 120 deg. and less than 240 deg., is radiographed using just one film holder, or;

(b) When a section or sections of a circumference, where the length between the ends of the outermost sections span less than 240 deg. is radiographed using more than one film holder.

(6) In *(4)* and *(5)* above, where other welds are radiographed simultaneously with the circumferential weld, one additional IQI shall be placed on each other weld.

(7) For segments of a flat or curved (i.e., ellipsoidal, torispherical, toriconical, elliptical, etc.) component where the source is placed perpendicular to the center of a length of weld for a single exposure when using more than three film holders, at least three IQIs, one placed at each end of the radiographed span and one in the approximate center of the span, are required.

(8) When an array of components in a circle is radiographed, at least one IQI shall show on each component image.

(9) In order to maintain the continuity of records involving subsequent exposures, all radiographs exhibiting IQIs that qualify the techniques permitted in accordance with *(1)* through *(7)* above shall be retained.

T-277.3 Shims Under Hole IQIs. For welds, a shim of material radiographically similar to the weld metal shall be placed between the part and the IQI, if needed, so that the radiographic density throughout the area of interest is no more than minus 15% from (lighter than) the radiographic density through the IQI.

The shim dimensions shall exceed the IQI dimensions such that the outline of at least three sides of the IQI image shall be visible in the radiograph.

T-280 EVALUATION

T-281 Quality of Radiographs

All radiographs shall be free from mechanical, chemical, or other blemishes to the extent that they do not mask and are not confused with the image of any discontinuity in the area of interest of the object being radiographed. Such blemishes include, but are not limited to:

(a) fogging;

(b) processing defects such as streaks, watermarks, or chemical stains;

(c) scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears;

(d) false indications due to defective screens.

T-282 Radiographic Density

T-282.1 Density Limitations. The transmitted film density through the radiographic image of the body of the appropriate hole IQI or adjacent to the designated wire of a wire IQI and the area of interest shall be 1.8 minimum for single film viewing for radiographs made with an X-ray source and 2.0 minimum for radiographs made with a gamma ray source. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.3. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

T-282.2 Density Variation

(a) General. If the density of the radiograph anywhere through the area of interest varies by more than minus 15% or plus 30% from the density through the body of the hole IQI or adjacent to the designated wire of a wire IQI, within the minimum/maximum allowable density ranges specified in T-282.1, then an additional IQI shall be used for each exceptional area or areas and the radiograph retaken. When calculating the allowable variation in density, the calculation may be rounded to the nearest 0.1 within the range specified in T-282.1.

(b) With Shims. When shims are used with hole-type IQIs, the plus 30% density restriction of (a) above may

TABLE T-283
EQUIVALENT HOLE-TYPE IQI SENSITIVITY

Hole-Type Designation	Equivalent Hole-Type Designations	
2*T* Hole	1*T* Hole	4*T* Hole
10	15	5
12	17	7
15	20	10
17	25	12
20	30	15
25	35	17
30	40	20
35	50	25
40	60	30
50	70	35
60	80	40
80	120	60
100	140	70
120	160	80
160	240	120
200	280	140

be exceeded, and the minimum density requirements of T-282.1 do not apply for the IQI, provided the required IQI sensitivity of T-283.1 is met.

T-283 IQI Sensitivity

T-283.1 Required Sensitivity. Radiography shall be performed with a technique of sufficient sensitivity to display the designated hole IQI image and the 2*T* hole, or the essential wire of a wire IQI. The radiographs shall also display the IQI identifying numbers and letters. If the designated hole IQI image and 2*T* hole, or essential wire, do not show on any film in a multiple film technique, but do show in composite film viewing, interpretation shall be permitted only by composite film viewing.

04 A06 **T-283.2 Equivalent Hole-Type Sensitivity.** A thinner or thicker hole-type IQI than the required IQI may be substituted, provided an equivalent or better IQI sensitivity, as listed in Table T-283, is achieved and all other requirements for radiography are met. Equivalent IQI sensitivity is shown in any row of Table T-283 which contains the required IQI and hole. Better IQI sensitivity is shown in any row of Table T-283 which is above the equivalent sensitivity row. If the required IQI and hole are not represented in the table, the next thinner IQI row from Table T-283 may be used to establish equivalent IQI sensitivity.

T-284 Excessive Backscatter

If a light image of the "B," as described in T-223, appears on a darker background of the radiograph, protection from backscatter is insufficient and the radiograph shall be considered unacceptable. A dark image of the "B" on a lighter background is not cause for rejection.

T-285 Evaluation by Manufacturer 04

The Manufacturer shall be responsible for the review, interpretation, evaluation, and acceptance of the completed radiographs to assure compliance with the requirements of Article 2 and the referencing Code Section. As an aid to the review and evaluation, the radiographic technique documentation required by T-291 shall be completed prior to the evaluation. The radiograph review form required by T-292 shall be completed during the evaluation. The radiographic technique details and the radiograph review form documentation shall accompany the radiographs. Acceptance shall be completed prior to presentation of the radiographs and accompanying documentation to the Inspector.

T-290 DOCUMENTATION

T-291 Radiographic Technique Documentation Details 04

The Manufacturer shall prepare and document the radiographic technique details. As a minimum, the following information shall be provided.

(*a*) identification as required by T-224

(*b*) the dimensional map (if used) of marker placement in accordance with T-275.3

(*c*) number of radiographs (exposures)

(*d*) X-ray voltage or isotope type used

(*e*) source size (*F* in T-274.1)

(*f*) base material type and thickness, weld thickness, weld reinforcement thickness, as applicable

(*g*) source-to-object distance (*D* in T-274.1)

(*h*) distance from source side of object to film (*d* in T-274.1)

(*i*) film manufacturer and Manufacturer's type/designation

(*j*) number of film in each film holder/cassette

(*k*) single- or double-wall exposure

(*l*) single- or double-wall viewing

T-292 Radiograph Review Form

The Manufacturer shall prepare a radiograph review form. As a minimum, the following information shall be provided.

(a) a listing of each radiograph location

(b) the information required in T-291, by inclusion or by reference

(c) evaluation and disposition of the material(s) or weld(s) examined

(d) identification (name) of the Manufacturer's representative who performed the final acceptance of the radiographs

(e) date of Manufacturer's evaluation

ARTICLE 2
MANDATORY APPENDIX

APPENDIX I — IN-MOTION RADIOGRAPHY

I-210 SCOPE

In-motion radiography is a technique of radiography where the object being radiographed and/or the source of radiation is in motion during the exposure.

In-motion radiography may be performed on weldments when the following modified provisions to those in Article 2 are satisfied.

I-220 GENERAL REQUIREMENTS

I-223 Backscatter Detection Symbol Location

(a) For longitudinal welds the lead symbol "B" shall be attached to the back of each film cassette or at approximately equal intervals not exceeding 36 in. (914 mm) apart, whichever is smaller.

(b) For circumferential welds, the lead symbol "B" shall be attached to the back of the film cassette in each quadrant or spaced no greater than 36 in. (914 mm), whichever is smaller.

I-260 CALIBRATION

I-263 Beam Width

The beam width shall be controlled by a metal diaphragm such as lead. The diaphragm for the energy selected shall be at least 10 half value layers thick.

The beam width as shown in Fig. I-263 shall be determined in accordance with:

$$w = \frac{c\,(F + a)}{b} + a$$

where

w = beam width at the source side of the weld measured in the direction of motion
a = slit width in diaphragm in direction of motion
b = distance from source to the weld side of the diaphragm
c = distance from weld side of the diaphragm to the source side of the weld surface
F = source size: the maximum projected dimension of the radiating source (or focal spot) in the plane perpendicular to the distance $b + c$ from the weld being radiographed

NOTE: Use consistent units.

I-270 EXAMINATION

I-274 Geometric and In-Motion Unsharpness

I-274.1 Geometric Unsharpness. Geometric unsharpness for in-motion radiography shall be determined in accordance with T-274.1. 04

I-274.2 In-Motion Unsharpness. In-motion unsharpness of the radiograph shall be determined in accordance with:

$$U_M = \frac{wd}{D}$$

where

U_M = in-motion unsharpness
w = beam width at the source side of the weld measured in the direction of motion determined as specified in I-263
d = distance from source side of the weld being radiographed to the film
D = distance from source of radiation to weld being radiographed

NOTE: Use consistent units.

I-274.3 Unsharpness Limitations. Recommended maximum values for geometric unsharpness and in-motion unsharpness are provided in T-274.2. 04

I-275 Location Markers

Location markers shall be placed adjacent to the weld at the extremity of each film cassette and also at approximately equal intervals not exceeding 15 in. (381 mm).

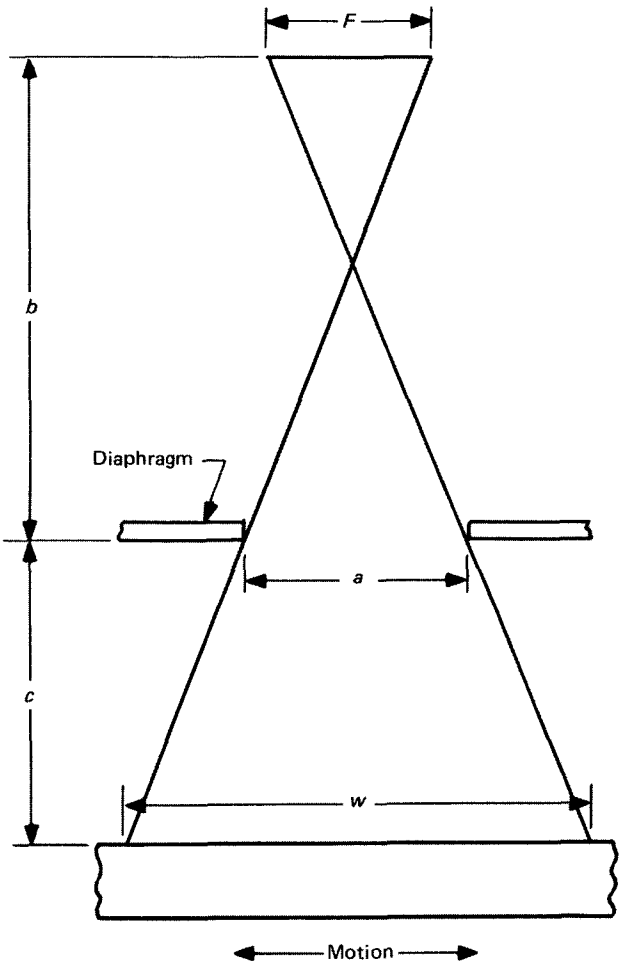


FIG. I-263 BEAM WIDTH DETERMINATION

I-277 Placement and Number of IQIs

(a) For longitudinal welds, hole IQIs shall be placed adjacent to and on each side of the weld seam, or on the weld seam at the beginning and end of the weld seam, and thereafter at approximately equal intervals not exceeding 36 in. (914 mm) or for each film cassette. Wire IQIs, when used, shall be placed on the weld seam so that the length of the wires is perpendicular to the length of the weld and spaced as indicated above for hole IQIs.

(b) For circumferential welds, hole IQIs shall be placed adjacent to and on each side of the weld seam or on the weld seam in each quadrant or spaced no greater than 36 in. (914 mm) apart, whichever is smaller. Wire IQIs, when used, shall be placed on the weld seam so that the length of the wires is perpendicular to the length of the weld and spaced as indicated above for hole IQIs.

I-279 Repaired Area

When radiography of a repaired area is required, the length of the film used shall be at least equal to the length of the original location marker interval.

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MANDATORY APPENDIX

APPENDIX II — REAL-TIME RADIOSCOPIC EXAMINATION

II-210 SCOPE

Real-time radioscopy provides immediate response imaging with the capability to follow motion of the inspected part. This includes radioscopy where the motion of the test object must be limited (commonly referred to as near real-time radioscopy).

Real-time radioscopy may be performed on materials including castings and weldments when the modified provisions to Article 2 as indicated herein are satisfied. SE-1255 shall be used in conjunction with this Appendix as indicated by specific references in appropriate paragraphs. SE-1416 provides additional information that may be used for radioscopic examination of welds.

II-220 GENERAL REQUIREMENTS

This radioscopic methodology may be used for the examination of ferrous or nonferrous materials and weldments.

II-221 Procedure Requirements

A written procedure is required and shall contain as a minimum the following (see SE-1255, 5.2):

(a) material and thickness range
(b) equipment qualifications
(c) test object scan plan
(d) radioscopic parameters
(e) image processing parameters
(f) image display parameters
(g) image archiving

II-230 EQUIPMENT AND MATERIALS

II-231 Radioscopic Examination Record

The radioscopic examination data shall be recorded and stored on videotape, magnetic disk, or optical disk.

II-235 Calibration Block

The calibration block shall be made of the same material type and product form as the test object. The calibration block may be an actual test object or may be fabricated to simulate the test object with known discontinuities.

II-236 Calibrated Line Pair Test Pattern and Step Wedge

The line pair test pattern shall be used without an additional absorber to evaluate the system resolution. The step wedge shall be used to evaluate system contrast sensitivity.

The step wedge must be made of the same material as the test object with steps representing 100%, 99%, 98%, and 97% of both the thickest and the thinnest material sections to be inspected. Additional step thicknesses are permissible.

II-237 Equivalent Performance Level

A system which exhibits a spatial resolution of 3 line pairs per millimeter, a thin section contrast sensitivity of 3%, and a thick section contrast sensitivity of 2% has an equivalent performance level of 3% — 2% — 3 lp/mm.

II-260 CALIBRATION

System calibration shall be performed in the static mode by satisfying the line pair test pattern resolution, step wedge contrast sensitivity, and calibration block discontinuity detection necessary to meet the IQI requirements of T-276.

II-263 System Performance Measurement

Real-time radioscopic system performance parameters shall be determined initially and monitored regularly with the system in operation to assure consistent results. The system performance shall be monitored at sufficiently

scheduled intervals to minimize the probability of time-dependent performance variations. System performance tests require the use of the calibration block, line pair test pattern, and the step wedge.

System performance measurement techniques shall be standardized so that they may be readily duplicated at the specified intervals.

II-264 Measurement With a Calibration Block

The calibration block shall also be placed in the same position as the actual object and manipulated through the same range and speed of motions as will be used for the actual object to demonstrate the system's response in the dynamic mode.

II-270 EXAMINATION

II-278 System Configuration

The radioscopic examination system shall, as a minimum, include the following:

(a) radiation source
(b) manipulation system
(c) detection system
(d) information processing system
(e) image display system
(f) record archiving system

II-280 EVALUATION

II-286 Factors Affecting System Performance

The radioscopic examination system performance quality is determined by the combined performance of the components specified in II-278. (See SE-1255, 6.1.)

When using wire IQIs, the radioscopic examination system may exhibit asymmetrical sensitivity, therefore, the wire diameter axis shall be oriented along the axis of the least sensitivity of the system.

II-290 DOCUMENTATION

II-291 Radioscopic Technique Information

To aid in proper interpretation of the radioscopic examination data, details of the technique used shall accompany the data. As a minimum, the information shall include the items specified in T-291 when applicable, II-221, and the following:

(a) operator identification
(b) system performance test data

II-292 Evaluation by Manufacturer

Prior to being presented to the Inspector for acceptance, the examination data shall be interpreted by the Manufacturer as complying with the referencing Code Section. The Manufacturer shall record the interpretation and disposition of each weldment examined on a radiographic interpretation review form accompanying the radioscopic data.

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MANDATORY APPENDIX

APPENDIX III — DIGITAL IMAGE ACQUISITION, DISPLAY, AND STORAGE FOR RADIOGRAPHY AND RADIOSCOPY

III-210 SCOPE

Digital image acquisition, display, and storage can be applied to radiography and radioscopy. Once the analog image is converted to digital format, the data can be displayed, processed, quantified, stored, retrieved, and converted back to the original analog format, for example, film or video presentation.

Digital imaging of all radiographic and radioscopic examination test results shall be performed in accordance with the modified provisions to Article 2 as indicated herein.

III-220 GENERAL REQUIREMENTS

III-221 Procedure Requirements

A written procedure is required and shall contain, as a minimum, the following system performance parameters:

(a) image digitizing parameters — modulation transfer function (MTF), line pair resolution, contrast sensitivity, and dynamic range;

(b) image display parameters — format, contrast, and magnification;

(c) image processing parameters that are used;

(d) storage — identification, data compression, and media (including precautions to be taken to avoid data loss);

(e) analog output formats.

III-222 Original Image Artifacts

Any artifacts that are identified in the original image shall be noted or annotated on the digital image.

III-230 EQUIPMENT AND MATERIALS

III-231 Digital Image Examination Record

The digital image examination data shall be recorded and stored on video tape, magnetic disk, or optical disk.

III-234 Viewing Considerations

The digital image shall be judged by visual comparison to be equivalent to the image quality of the original image at the time of digitization.

III-236 Calibrated Optical Line Pair Test Pattern and Optical Density Step Wedge

An optical line pair test pattern operating between 0.1 and 4.0 optical density shall be used to evaluate the modulation transfer function (MTF) of the system. The optical density step wedge shall be used to evaluate system contrast sensitivity.

III-250 IMAGE ACQUISITION AND STORAGE

III-255 Area of Interest

Any portion of the image data may be digitized and stored provided the information that is digitized and stored includes the area of interest as defined by the referencing Code Section.

III-258 System Configuration

The system shall, as a minimum, include the following:

(a) digitizing system

(b) display system

(c) image processing system

(d) image storage system

III-260 CALIBRATION

The system shall be calibrated for modulation transfer function (MTF), dynamic range, and contrast sensitivity.

III-263 System Performance Measurement

System performance parameters (as noted in III-221) shall be determined initially and monitored regularly with

the system in operation to assure consistent results. The system performance shall be monitored at the beginning and end of each shift to minimize the probability of time-dependent performance variations.

III-280 EVALUATION

III-286 Factors Affecting System Performance

The quality of system performance is determined by the combined performance of the components specified in III-258.

III-287 System-Induced Artifacts

The digital images shall be free of system-induced artifacts in the area of interest that could mask or be confused with the image of any discontinuity in the original analog image.

III-290 DOCUMENTATION

III-291 Digital Imaging Technique Information

To aid in proper interpretation of the digital examination data, details of the technique used shall accompany the data. As a minimum, the information shall include items specified in T-291 and II-221 when applicable, III-221, III-222, and the following:

(a) operator identification

(b) system performance test data

III-292 Evaluation by Manufacturer

Prior to being presented to the Inspector for acceptance, the digital examination data from a radiographic or radioscopic image shall have been interpreted by the Manufacturer as complying with the referencing Code Section.

The digital examination data from a radiograph that has previously been accepted by the Inspector is not required to be submitted to the Inspector for acceptance.

ARTICLE 2
MANDATORY APPENDIX

APPENDIX IV — INTERPRETATION, EVALUATION, AND DISPOSITION OF RADIOGRAPHIC AND RADIOSCOPIC EXAMINATION TEST RESULTS PRODUCED BY THE DIGITAL IMAGE ACQUISITION AND DISPLAY PROCESS

IV-210 SCOPE

The digital image examination test results produced in accordance with Article 2, Mandatory Appendix II, and Article 2, Mandatory Appendix III, may be interpreted and evaluated for final disposition in accordance with the additional provisions to Article 2 as indicated herein.

The digital information is obtained in series with radiography and in parallel with radioscopy. This data collection process also provides for interpretation, evaluation, and disposition of the examination test results.

A05

IV-220 GENERAL REQUIREMENTS

The digital image shall be interpreted while displayed on the monitor. The interpretation may include density and contrast adjustment, quantification, and pixel measurement, including digital or optical density values and linear or area measurement.

The interpretation of a digitized image is dependent upon the same subjective evaluation by a trained interpreter as the interpretation of a radiographic or radioscopic image. Some of the significant parameters considered during interpretation include: area of interest, image quality, IQI image, magnification, density, contrast, discontinuity shape (rounded, linear, irregular), and artifact identification.

The digital image interpretation of the radiographic and radioscopic examination test results shall be performed in accordance with the modified provisions to Article 2 as indicated herein.

After the interpretation has been completed, the interpretation data and the digital image, which shall include the unprocessed original full image and the digitally processed image, shall be recorded and stored on video tape, magnetic tape, or optical disk.

IV-221 Procedure Requirements

A written procedure is required and shall contain, as a minimum, the following system performance parameters:

(a) image digitizing parameters — modulation transfer function (MTF), line pair resolution, contrast sensitivity, dynamic range, and pixel size;

(b) image display parameters — monitor size including display pixel size, luminosity, format, contrast, and magnification;

(c) signal processing parameters — including density shift, contrast stretch, log transform, and any other techniques that do not mathematically alter the original digital data, e.g., linear and area measurement, pixel sizing, and value determination;

(d) storage — identification, data compression, and media (including precautions to be taken to avoid data loss). The non-erasable optical media should be used for archival applications. This is frequently called the WORM (Write Once Read Many) technology. When storage is accomplished on magnetic or erasable optical media, then procedures must be included that show trackable safeguards to prevent data tampering and guarantee data integrity.

IV-222 Original Image Artifacts

Any artifacts that are identified shall be noted or annotated on the digital image.

IV-230 EQUIPMENT AND MATERIALS

IV-231 Digital Image Examination Record

The digital image examination data shall be recorded and stored on video tape, magnetic disk, or optical disk.

IV-234 Viewing Considerations

The digital image shall be evaluated using appropriate monitor luminosity, display techniques, and room lighting to insure proper visualization of detail.

IV-236 Calibrated Optical Line Pair Test Pattern and Optical Density Step Wedge

An optical line pair test pattern operating between 0.1 and 4.0 optical density shall be used to evaluate the modulation transfer function (MTF) of the system. High spatial resolution with 14 line-pairs per millimeter (lp/mm) translates to a pixel size of 0.0014 in. (0.035 mm). Lesser spatial resolution with 2 lp/mm can be accomplished with a pixel size of 0.012 in. (0.3 mm). The optical density step wedge shall be used to evaluate system contrast sensitivity. Alternatively, a contrast sensitivity gage (step wedge block) in accordance with SE-1647 may be used.

IV-250 IMAGE ACQUISITION, STORAGE, AND INTERPRETATION

IV-255 Area of Interest

The evaluation of the digital image shall include all areas of the image defined as the area of interest by the referencing Code Section.

IV-258 System Configuration

The system shall, as a minimum, include:

(a) digital image acquisition system
(b) display system
(c) image processing system
(d) image storage system

IV-260 CALIBRATION

The system shall be calibrated for modulation transfer function (MTF), dynamic range, and contrast sensitivity. The electrical performance of the hardware and the quality of the digital image shall be measured and recorded.

IV-263 System Performance Measurement

System performance parameters (as noted in IV-221) shall be determined initially and monitored regularly with the system in operation to assure consistent results. The system performance shall be monitored at the beginning and end of each shift to minimize the probability of time-dependent performance variations.

IV-280 EVALUATION

IV-286 Factors Affecting System Performance

The quality of system performance is determined by the combined performance of the components specified in IV-258.

IV-287 System-Induced Artifacts

The digital images shall be free of system-induced artifacts in the area of interest that could mask or be confused with the image of any discontinuity.

IV-290 DOCUMENTATION

IV-291 Digital Imaging Technique Information

To aid in proper interpretation of the digital examination data, details of the technique used shall accompany the data. As a minimum, the information shall include items specified in T-291 and II-221 when applicable, III-221, III-222, IV-221, IV-222, and the following:

(a) operator identification
(b) system performance test data
(c) calibration test data

IV-292 Evaluation by Manufacturer

Prior to being presented to the Inspector for acceptance, the digital examination data from a radiographic or radioscopic image shall have been interpreted by the Manufacturer as complying with the referencing Code Section.

The digitized examination data that has previously been accepted by the Inspector is not required to be submitted to the Inspector for acceptance.

ARTICLE 2
MANDATORY APPENDIX

APPENDIX V — GLOSSARY OF TERMS FOR RADIOGRAPHIC EXAMINATION

V-210 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms relating to radiographic examination.

V-220 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 7 provides the definitions of terms listed in V-230(a).

(c) For general terms, such as *Indication, Flaw, Discontinuity, Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph V-230(b) provides a list of terms and definitions that are Code specific. Paragraph V-230(c) provides a list of terms and definitions that are specific to Section V, Article 2, Appendix VI.

A05 **V-230 REQUIREMENTS**

A06 *(a)* The following SE-1316 terms are used in conjunction with this Article: *analog image, back scattered radiation, cassette, composite viewing, contrast sensitivity, contrast stretch, densitometer, density* (film), *digital, digital image, digitize, digital image acquisition system, erasable optical medium, focal spot, fog, geometric unsharpness, intensifying screen, IQI sensitivity, line pair per millimeter, line pair test pattern, location marker, luminosity, magnetic storage medium, optical density, photostimulable luminescent phosphor, pixel, pixel size, recording media, screen, source, step wedge, system-induced artifacts, transmission densitometer,* and *transmitted film density.*

A06 *(b)* The following Code terms are used in conjunction with this Article.

annotate — to provide an explanatory note on the digital image

calibrated line pair test pattern — see *optical line pair test pattern*

calibrated step wedge film — a radiograph with discrete density steps, which is traceable to a national standard

data compression — a reduction in the size of a digital data set to a smaller data set

density shift — a function that raises or lowers all density/greyscale values equally such that contrast is maintained within the data set

designated wire — the specific wire that must be discernible in the radiographic image of a wire-type image quality indicator

diaphragm — an aperture (opening) in a radiation opaque material that limits the usable beam size of a radiation source

display pixel size — the length and width dimensions of the smallest element of a displayed image

dynamic range — the range of operation of a device between its upper and lower limit; this range can be given as a ratio (e.g., 100:1) of the maximum signal level capability to its noise level, the number of measurable steps between the upper and lower limits, the number of bits needed to record this number of measurable steps, or the maximum and minimum measurable values

equivalent IQI sensitivity — that thickness of hole-type IQI, expressed as a percentage of the part thickness, in which 2*T* hole would be visible under the same radiographic conditions

essential hole — the specific hole that must be discernible in the radiographic image of a hole-type IQI

image processing system — a system that uses mathematical algorithms to manipulate digital image data

image quality indicator

hole type — a rectangular plaque, made of material radiographically similar to that of the object being radiographed, with small diameter holes (1*T*, 2*T*, and 4*T*) used to check the image quality of the radiograph

wire type — a set of small diameter wires, made of material radiographically similar to that of the object being radiographed, used to check the image quality of the radiograph

image storage system — a system that can store digital image data for future use

IQI — image quality indicator

line pair resolution — the number of line pairs per unit distance that are detectable in an image

log transform — a function that applies a logarithmic mapping to all density/greyscale values in an image; this operation is often performed when the resulting distribution is normal, or if the resulting relationship with another variable is linear

modulation transfer function (MTF) — a measure of spatial resolution as a function of contrast; a plot of these variables (spatial resolution and contrast) yields a curve representing the frequency response of the system

national standard step tablet — an x-ray film with discrete density steps produced and certified by a nationally recognized standardizing body

nonerasable optical media (optical disk) — a storage media that prevents the erasure or alteration of digital data after it is stored

optical density step wedge — a radiographic image of a mechanical step wedge with precise thickness increments and may be used to correlate optical film density to the thickness of material, also known as a step tablet

penetrameter — no longer used in Article 2; see *image quality indicator*

quantification — the act of determining or expressing a quantity (i.e., giving a numerical value to a measurement of something)

radiograph — a visible image viewed for acceptance which is created by penetrating radiation acting on a recording media; either film on a viewer or electronic images on a monitor

radiographic examination — a nondestructive method for detecting discontinuities in materials and components using penetrating radiation and recording media to produce an image

sensitivity — the smallest discernible detail and/or contrast change (e.g., IQI hole or wire) in a radiographic image

shim — a material, radiographically similar to the object being radiographed, that is placed between a hole-type IQI and the object in order to reduce the radiographic density through the image of the hole-type IQI

source side — that surface of the area of interest being radiographed for evaluation nearest the source of radiation

step wedge calibration film — a processed film with discrete density steps that have been verified by comparison with a national standard step tablet

step wedge comparison film — a processed film with discrete density steps that have been verified by use of a calibrated densitometer, which is used to determine if production radiographs meet density limits

WORM (write once read many) — a term relating to a type of digital storage media where the data can be stored only once but accessed (nondestructively) many times

(c) The following Code terms are used in conjunction with Article 2, Appendix VI:

contrast sensitivity — the size of the smallest detectable change in optical density

dynamic range — the extent of measurable optical density obtained in a single scan

image — the digital representation of a target on the reference film used to evaluate both the digitization and display aspects of a film digitization system

reference film — a single industrial radiographic film that encompasses the targets necessary for the evaluation and quantification of the performance characteristics of a film digitization system

spatial linearity — the accuracy to which a digitization system reproduces the physical dimensions of information on the original film [both in the horizontal (along a single scan line) and vertical (from one scan line to another) directions]

spatial resolution — the size of the smallest detectable element of the digitized image

target — a physical pattern on a reference film used to evaluate the performance of a film digitization system

ARTICLE 2
MANDATORY APPENDIX

APPENDIX VI — DIGITAL IMAGE ACQUISITION, DISPLAY, INTERPRETATION, AND STORAGE OF RADIOGRAPHS FOR NUCLEAR APPLICATIONS

VI-210 SCOPE

Digital imaging process and technology provide the ability to digitize and store the detailed information contained in the radiograph (analog image), thus eliminating the need to maintain and store radiographs for permanent record.

VI-220 GENERAL REQUIREMENTS

VI-221 Supplemental Requirements

VI-221.1 Additional Information. Article 2, Mandatory Appendices III and IV, contain additional information that shall be used to supplement the requirements of this Appendix. These supplemental requirements shall be documented in the written procedure required by this Appendix.

VI-221.2 Reference Film. Supplement A contains requirements for the manufacture of the reference film.

VI-222 Written Procedure

A written procedure is required. The written procedure shall be the responsibility of the owner of the radiographs and shall be demonstrated to the satisfaction of the Authorized Nuclear Inspector (ANI). When other enforcement or regulatory agencies are involved, the agency approval is required by formal agreement. The written procedure shall include, as a minimum, the following essential variables:

VI-222.1 Digitizing System Description

(a) manufacturer and model no. of digitizing system;

(b) physical size of the usable area of the image monitor;

(c) film size capacity of the scanning device;

(d) spot size(s) of the film scanning system;

(e) image display pixel size as defined by the vertical/horizontal resolution limits of the monitor;

(f) luminance of the video display; and

(g) data storage medium.

VI-222.2 Digitizing Technique

(a) digitizer spot size (in microns) to be used (see VI-232);

(b) loss-less data compression technique, if used;

(c) method of image capture verification;

(d) image processing operations;

(e) time period for system verification (see VI-264);

(f) spatial resolution used (see VI-241);

(g) contrast sensitivity (density range obtained) (see VI-242);

(h) dynamic range used (see VI-243); and

(i) spatial linearity of the system (see VI-244).

VI-223 Personnel Requirements

Personnel shall be qualified as follows:

(a) Level II and Level III Personnel. Level II and Level III personnel shall be qualified in the radiographic method as required by Article 1. In addition, the employer's written practice shall describe the specific training and practical experience of Level II and Level III personnel involved in the application of the digital imaging process and the interpretation of results and acceptance of system performance. Training and experience shall be documented in the individual's certification records.

(b) As a minimum, Level II and III individuals shall have 40 hours of training and 1 month of practical experience in the digital imaging process technique.

(c) Other Personnel. Personnel with limited qualifications performing operations other than those required for the Level II or Level III shall be qualified in accordance with Article 1. Each individual shall have specified training and practical experience in the operations to be performed.

VI-230 EQUIPMENT AND MATERIALS

VI-231 System Features

The following features shall be common to all digital image processing systems:

(a) noninterlaced image display format;

(b) *WORM* — write-once/read-many data storage; and

(c) fully reversible (loss-less) data compression (if data compression is used).

VI-232 System Spot Size

The spot size of the digitizing system shall be:

(a) 70 microns, or smaller for radiographs made with energies up to 1 MeV; or

(b) 100 microns or smaller for radiographs made with energies over 1 MeV.

VI-240 SYSTEM PERFORMANCE REQUIREMENTS

System performance shall be determined using the digitized representation of the reference targets (images). No adjustment shall be made to the digitizing system which may affect system performance after recording the reference targets.

VI-241 Spatial Resolution

Spatial resolution shall be determined as described in VI-251. The system shall be capable of resolving a pattern of 7 line pairs/millimeter (lp/mm) for systems digitizing with a spot size of 70 microns or less, or 5 line pairs/millimeter for spot sizes greater than 70 microns.

VI-242 Contrast Sensitivity

Contrast sensitivity shall be determined as described in VI-252. The system shall have a minimum contrast sensitivity of 0.02 optical density.

VI-243 Dynamic Range

Dynamic range shall be determined as described in VI-253. The system shall have a minimum dynamic range of 3.5 optical density.

VI-244 Spatial Linearity

Spatial linearity shall be determined as described in VI-254. The system shall return measured dimensions with 3% of the actual dimensions on the reference film.

VI-250 TECHNIQUE

The reference film described in Supplement A and Fig. VI-A-1 shall be used to determine the performance of the digitization system. The system settings shall be adjusted to optimize the display representation of the reference targets (images). The reference film and all subsequent radiographs shall be scanned by the digitization system using these optimized settings.

VI-251 Spatial Resolution Evaluation

At least two of the converging line pair images (0 deg., 45 deg., and 90 deg. line pairs) shall be selected near the opposite corners of the digitizing field and one image near the center of the digitized reference film. The spatial resolution in each position and for each orientation shall be recorded as the highest indicated spatial frequency (as determined by the reference lines provided) where all of the lighter lines are observed to be separated by the darker lines. The system resolution shall be reported as the poorest spatial resolution obtained from all of the resolution images evaluated.

VI-252 Contrast Sensitivity Evaluation

Using the contrast sensitivity images and the digitized stepped density scale images to evaluate the detectability of each density step (the observed density changes shall be indicative of the system's capability to discern 0.02 density differences), the detectability of each density step and the difference in density between steps shall be evaluated.

VI-253 Dynamic Range Evaluation

The dynamic range of the digitization system shall be determined by finding the last visible density step at both ends of the density strip. The dynamic range shall be measured to the nearest 0.50 optical density.

VI-254 Spatial Linearity Evaluation

The digitization system shall be set to read the inch scale on the reference film. The measurement tool shall then be used to measure the scale in a vertical direction and horizontal direction. The actual dimension is divided by the measured dimension to find the percentage of error in the horizontal and vertical directions.

VI-260 DEMONSTRATION OF SYSTEM PERFORMANCE

VI-261 Procedure Demonstration

The written procedure described in VI-222 shall be demonstrated to the ANI and, if requested, the regulatory

agency, as having the ability to acquire, display, and reproduce the analog images from radiographs. Evidence of the demonstration shall be recorded as required by VI-291.

VI-262 Processed Targets

The digitizing process and equipment shall acquire and display the targets described in Supplement A. The digitally processed targets of the reference film shall be used to verify the system performance.

VI-263 Changes in Essential Variables

Any change in the essential variables identified in VI-222 and used to produce the results in VI-250 shall be cause for reverification of the System Performance.

VI-264 Frequency of Verification

The System Performance shall be initially verified in accordance with VI-262 at the beginning of each digitizing shift. Reverification in accordance with VI-262 shall take place at the end of each shift or at the end of 12 continuous hours, whichever is less, or at any time that malfunctioning is suspected.

VI-265 Changes in System Performance

Any evidence of change in the System Performance specified in VI-240 shall invalidate the digital images processed since the last successful verification and shall be cause for reverification.

VI-270 EXAMINATION

VI-271 System Performance Requirements

The digitizing system shall meet the requirements specified in VI-240 before digitizing archival radiographs.

VI-272 Artifacts

Radiographs shall be visually examined for foreign material and artifacts (e.g., scratches or water spots) in the area of interest. Foreign material not removed and artifacts observed shall be documented.

VI-273 Calibration

The calibration for a specific set of parameters (i.e., film size, density range, and spatial resolution) shall be conducted by following VI-240 and Supplement A. The results shall be documented.

VI-280 EVALUATION

VI-281 Process Evaluation

The Level II or Level III Examiner described in VI-223(a) shall be responsible for determining that the digital imaging process is capable of reproducing the original analog image. This digital image shall then be transferred to the write-once-read-many (WORM) optical disc.

VI-282 Interpretation

When interpretation of the radiograph is used for acceptance, the requirements of Article 2, Mandatory Appendix IV and the Referencing Code Section shall apply. If analog radiographs must be viewed in composite for acceptance, then both radiographs shall be digitized. The digital image of the analog radiographs shall be interpreted singularly.

VI-283 Baseline

Digital images of previously accepted radiographs may be used as a baseline for subsequent in-service inspections.

VI-290 DOCUMENTATION

VI-291 Reporting Requirements

The following shall be documented in a final report:

(a) spatial resolution (VI-241);

(b) contrast sensitivity (VI-242);

(c) frequency for system verification;

(d) dynamic range (VI-243);

(e) Traceability technique from original component to radiograph to displayed digital image, including original radiographic report(s). (The original radiographic reader sheet may be digitized to fulfill this requirement);

(f) condition of original radiographs (VI-281);

(g) procedure demonstration (VI-261);

(h) spatial linearity (VI-244);

(i) system performance parameters (VI-241); and

(j) personnel performing the digital imaging process (VI-223).

VI-292 Archiving

When the final report and digitized information are used to replace the analog radiograph as the permanent record as required by the referencing Code Section, all information pertaining to the original radiography shall be documented in the final report and processed as part of the digital record. A duplicate copy of the WORM

storage media is required if the radiographs are to be destroyed.

ARTICLE 2
MANDATORY APPENDIX VI — SUPPLEMENT A

VI-A-210 SCOPE

The reference film described in this supplement provides a set of targets suitable for evaluating and quantifying the performance characteristics of a radiographic digitizing system. The reference film is suitable for evaluating both the radiographic film digitization process and the electronic image reconstruction process.

The reference film shall be used to conduct performance demonstrations and evaluations of the digitizing system to verify the operating characteristics before radiographs are digitized. The reference film provides for the evaluation of spatial resolution, contrast sensitivity, dynamic range, and spatial linearity.

VI-A-220 GENERAL

VI-A-221 Reference Film

The reference film shall be specified in VI-A-230 and VI-A-240.

VI-A-230 EQUIPMENT AND MATERIALS

VI-A-231 Reference Targets

The illustration of the reference film and its targets is as shown in Fig. VI-A-1.

VI-A-232 Spatial Resolution Targets

The reference film shall contain spatial resolution targets as follows:

VI-A-232.1 Converging Line Pair Targets. Converging line pairs shall consist of 3 identical groups of no less than 6 converging line pairs (6 light lines and 6 dark lines). The targets shall have a maximum resolution of no less than 20 line pairs per millimeter (lp/mm) and a minimum resolution of no greater than 1 lp/mm. The 3 line pair groups shall be oriented in the vertical, horizontal, and the last group shall be 45 deg. from the previous two groups. The maximum resolution shall be oriented toward the corners of the film. Reference marks shall be provided to indicate spatial resolution at levels of no less than 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 lp/mm. The spatial resolution targets shall be located in each corner of the needed film sizes.

VI-A-232.2 Parallel Line Pair Targets. Parallel line pairs shall consist of parallel line pairs in at least the vertical direction on the reference film. It shall have a maximum resolution of at least 20 lp/mm and a minimum resolution of no less than 0.5 lp/mm. It shall have distinct resolutions of 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 20 lp/ mm and have the corresponding reference marks. It shall be located near the middle of the reference film.

VI-A-233 Constrast Sensitivity Targets

Contrast sensitivity targets shall consist of approximately 0.4 in. by 0.4 in. (10 mm by 10 mm) blocks centered in 1.6 in. by 1.6 in. (40 mm by 40 mm) blocks of a slightly lower density. Two series of these step blocks shall be used with an optical density of approximately 2.0 on a background of approximately 1.95, an optical density change of 0.05. The second block series will have an optical density of approximately 3.5 on a background of approximately 3.4, an optical density change of 0.10. The relative density change is more important than the absolute density. These images shall be located near the edges and the center of the film so as to test the contrast sensitivity throughout the scan path.

VI-A-234 Dynamic Range Targets

Stepped density targets shall consist of a series of 0.4 in. by 0.4 in. (10 mm by 10 mm) steps aligned in a row with densities ranging from 0.5 to 4.5 with no greater than 0.5 optical density steps. At four places on the density strip (at approximately 1.0, 2.0, 3.0, and 4.0 optical densities), there shall be optical density changes of 0.02 which shall also be used to test the contrast sensitivity. These stepped density targets shall be located near the edges of the film and near the center so as to test the dynamic range throughout the scan path.

VI-A-235 Spatial Linearity Targets

Measurement scale targets shall be located in the horizontal and vertical dimensions. The measurement scale targets shall be in English and/or metric divisions.

VI-A-240 MISCELLANEOUS REQUIREMENTS

Manufacturing specifications shall be minimum requirements necessary for producing the reference film. The reference film shall have a unique identification which appears as an image when digitized.

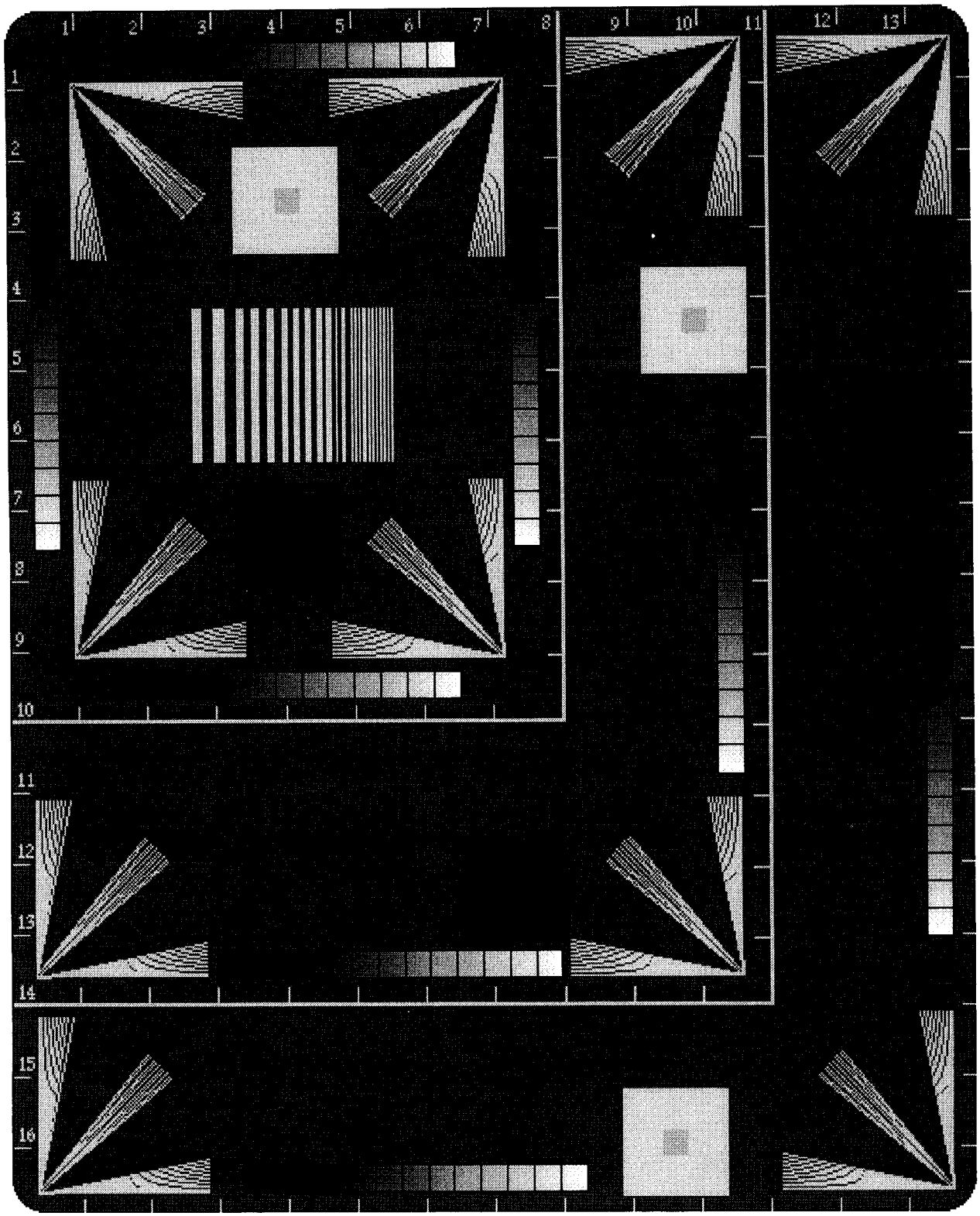

FIG. VI-A-1 REFERENCE FILM

VI-A-241 Material

The reference film shall be a fine grain, industrial type film. The film used will be of high quality so the required specifications in VI-A-230 are met.

VI-A-242 Film Size

The film size shall be sufficient to accommodate the largest area of interest to be digitized.

VI-A-243 Spatial Resolution

The spatial resolution shall be a minimum of 20 lp/mm.

VI-A-244 Density

The relative densities stated in VI-A-233 and VI-A-234 shall be within ±0.005 optical density.

(a) The tolerance for the optical density changes stated in VI-A-233 and VI-A-234 shall be ±0.005.

(b) The measured densities shall be within ±0.15 of the values stated in VI-A-233 and VI-A-234. The actual densities shall be recorded and furnished with the reference film.

(c) Density requirements shall be in accordance with ANSI IT-2.19.

(d) The background density, where there are no images located, shall have a 3.0 optical density ±0.5.

VI-A-245 Linearity

The measurement scale targets shall be accurately electronically produced to ±0.05 in. (±1.3 mm).

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MANDATORY APPENDIX

APPENDIX VII — RADIOGRAPHIC EXAMINATION OF METALLIC CASTINGS

VII-210 SCOPE

Metallic castings, due to their inherent complex configurations, present examination conditions that are unique to this product form.

Radiographic examination may be performed on castings when the modified provisions to Article 2, as indicated herein, are satisfied.

VII-220 GENERAL REQUIREMENTS

VII-224 System of Identification

A system shall be used to produce permanent identification on the radiograph traceable to the contract, component, or part numbers, as appropriate. In addition, each film of a casting being radiographed shall be plainly and permanently identified with the name or symbol of the Material Manufacturer, Certificate Holder, or Subcontractor, job or heat number, date, and, if applicable, repairs (R1, R2, etc.). This identification system does not necessarily require that the information appear as radiographic images. In any case, this information shall not obscure the area of interest.

VII-270 EXAMINATION

VII-271 Radiographic Technique

VII-271.2 Double-Wall Viewing Technique. A double-wall viewing technique may be used for cylindrical castings $3\frac{1}{2}$ in. (88 mm) or less in O.D. or when the shape of a casting precludes single-wall viewing.

VII-276 IQI Selection

VII-276.3 Additional IQI Selection Requirements. The thickness on which the IQI is based is the single-wall thickness.

(a) Casting Areas Prior to Finish Machining. The IQI shall be based on a thickness that does not exceed the finished thickness by more than 20% or $\frac{1}{4}$ in. (6 mm), whichever is greater. In no case shall an IQI size be based on a thickness greater than the thickness being radiographed.

(b) Casting Areas That Will Remain in the As-Cast Condition. The IQI shall be based on the thickness being radiographed.

VII-280 EVALUATION

VII-282 Radiographic Density

VII-282.1 Density Limitations. The transmitted film density through the radiographic image of the body of the appropriate hole IQI or adjacent to the designated wire of a wire IQI and the area of interest shall be 1.5 minimum for single film viewing. For composite viewing of multiple film exposures, each film of the composite set shall have a minimum density of 1.0. The maximum density shall be 4.0 for either single or composite viewing. A tolerance of 0.05 in density is allowed for variations between densitometer readings.

VII-290 DOCUMENTATION

VII-293 Layout Details[1]

To assure that all castings are radiographed consistently in the same manner, layout details shall be provided. As a minimum, the layout details shall include:

(a) sketches of the casting, in as many views as necessary, to show the approximate position of each location marker; and

(b) source angles if not perpendicular to the film.

[1] Sample layout and technique details are illustrated in SE-1030, Appendix (Nonmandatory Information) X1, Fig. X1.1, Radiographic Standard Shooting Sketch (RSS).

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MANDATORY APPENDIX

A05 ## APPENDIX VIII — RADIOGRAPHY USING PHOSPHOR IMAGING PLATE

VIII-210 SCOPE

This Appendix provides requirements for using phosphor imaging plate (photostimulable luminescent phosphor) as an alternative to film radiography.

Radiography using phosphor imaging plate may be performed on materials including castings and weldments when the modified provisions to Article 2 as indicated herein and all other requirements of Article 2 are satisfied. The term *film,* as used within Article 2, applicable to performing radiography in accordance with this Appendix, refers to phosphor imaging plate. Appendix III, Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy, shall be used where applicable.

VIII-220 GENERAL REQUIREMENTS

VIII-221 Procedure Requirements

VIII-221.1 Written Procedure. A written procedure is required. In lieu of the requirements of T-221.1, each procedure shall include at least the following information, as applicable:

(a) material type and thickness range

(b) isotope or maximum X-ray voltage used

(c) minimum source-to-object distance (*D* in T-274.1)

(d) distance from source side of object to the phosphor imaging plate (*d* in T-274.1)

(e) source size (*F* in T-274.1)

(f) phosphor imaging plate manufacturer and designation

(g) screens used

(h) image scanning and processing equipment manufacturer and model

VIII-221.2 Procedure Demonstration. Demonstration of image quality indicator (IQI) image requirements of the written procedure on production or technique radiographs using phosphor imaging plate shall be considered satisfactory evidence of compliance with that procedure.

VIII-225 Monitoring Density Limitations of Radiographs

The requirements of T-225 are not applicable to phosphor imaging plate radiography.

VIII-230 EQUIPMENT AND MATERIALS

VIII-231 Phosphor Imaging Plate

VIII-231.1 Selection. Radiography shall be performed using an industrial phosphor imaging plate capable of demonstrating IQI image requirements.

VIII-231.2 Processing. The system used for processing a phosphor imaging plate shall be capable of acquiring, storing, and displaying the digital image.

VIII-234 Facilities for Viewing of Radiographs

Viewing facilities shall provide subdued background lighting of an intensity that will not cause reflections, shadows, or glare on the monitor that interfere with the interpretation process.

VIII-260 CALIBRATION

VIII-262 Densitometer and Step Wedge Comparison Film

The requirements of T-262 are not applicable to phosphor imaging plate radiography.

VIII-270 EXAMINATION

VIII-277 Use of IQIs to Monitor Radiographic Examination

VIII-277.1 Placement of IQIs

(a) Source-Side IQI(s). When using separate blocks for IQI placement as described in T-277.1(a), the thickness of the blocks shall be such that the negative image brightness at the body of the IQI is equal to or greater than the image brightness at the area of interest.

All other requirements of T-277.1 shall apply.

VIII-277.2 Number of IQIs

(a) Multiple IQIs. An IQI shall be used for each applicable thickness range in Table T-276 spanned by the minimum-to-maximum thickness of the area of interest to be radiographed.

All other requirements of T-277.2 shall apply.

VIII-277.3 Shims Under Hole IQIs. For welds with reinforcement or backing material, a shim of material radiographically similar to the weld metal and/or backing material shall be placed between the part and the IQIs, such that the negative image brightness at the body of the IQI is equal to or greater than the image brightness at the area of interest.

The shim dimensions shall exceed the IQI dimensions such that the outline of at least three sides of the IQI shall be visible in the radiograph.

VIII-280 EVALUATION

VIII-281 System-Induced Artifacts

The digital image shall be free of system-induced artifacts in the area of interest that could mask or be confused with the image of any discontinuity.

VIII-282 Radiographic Density

The requirements of T-282 are not applicable to phosphor imaging plate radiography.

VIII-287 Measuring Scale

The measuring scale used for interpretation shall be capable of providing dimensions of the projected image. The measurement scale tool shall be based upon a known dimensional comparator that is placed on the cassette.

VIII-288 Interpretation

Final radiographic interpretation shall be made after the digital image displays the required IQI sensitivity.

VIII-290 DOCUMENTATION

VIII-291 Digital Imaging Technique Documentation Details

The Manufacturer shall prepare and document the radiographic technique details. As a minimum, the following information shall be provided:

(a) identification as required by T-224

(b) the dimensional map (if used) of marker placement in accordance with T-275.3

(c) number of exposures

(d) X-ray voltage or isotope used

(e) source size (*F* in T-274.1)

(f) base material type and thickness, weld reinforcement thickness, as applicable

(g) source-to-object distance (*D* in T-274.1)

(h) distance from source side of object to storage phosphor media (*d* in T-274.1)

(i) storage phosphor manufacturer and designation

(j) image acquisition (digitizing) equipment manufacturer, model, and serial number

(k) single- or double-wall exposure

(l) single- or double-wall viewing

(m) procedure identification and revision level

(n) imaging software version and revision

(o) numerical values of the final image processing parameters, i.e., filters, window (contrast), and level (brightness) for each view

The technique details may be embedded in the data file. When this is performed, ASTM E 1475, Standard Guide for Data Fields for Computerized Transfer of Digital Radiological Test Data, may be used as a guide for establishing data fields and information content.

ARTICLE 2
NONMANDATORY APPENDIX

04

APPENDIX A — RECOMMENDED RADIOGRAPHIC TECHNIQUE SKETCHES FOR PIPE OR TUBE WELDS

A-210 SCOPE

The sketches in this Appendix illustrate techniques used in the radiographic examination of pipe or tube welds.

Other techniques may be used.

FIG. A-210-1 SINGLE-WALL RADIOGRAPHIC TECHNIQUES

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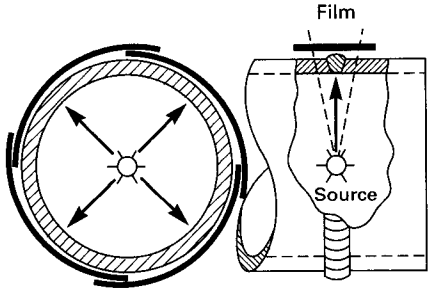
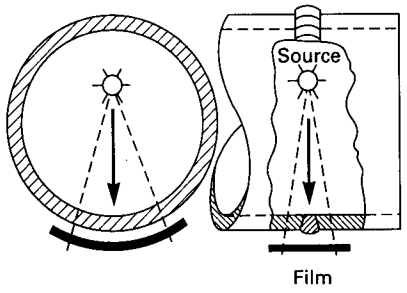
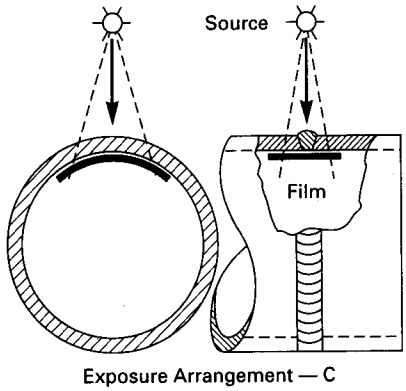
O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement		IQI		Location Marker Placement
			End View	Side View	Selection	Placement	
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — A		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Either Side T-275.3 T-275.1(c)
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — B		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1 (b)(1)
Any	Single-Wall T-271.1	Single-Wall	 Exposure Arrangement — C		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Source Side T-275.1 (a)(3)

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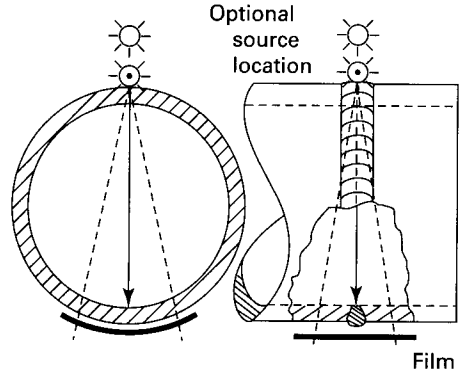
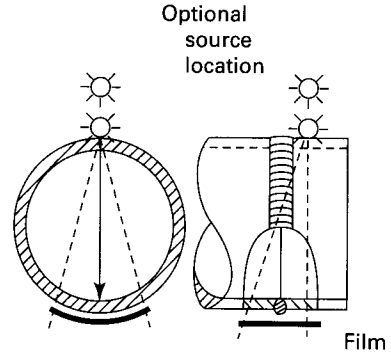
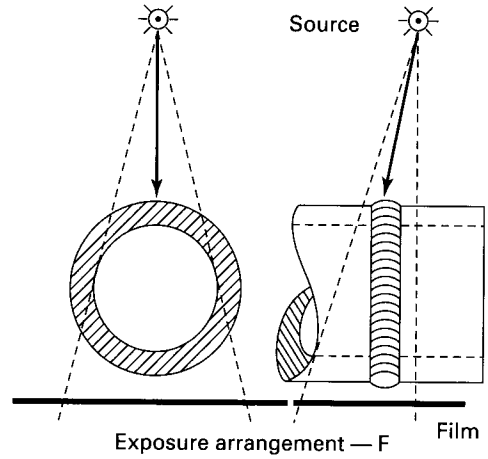
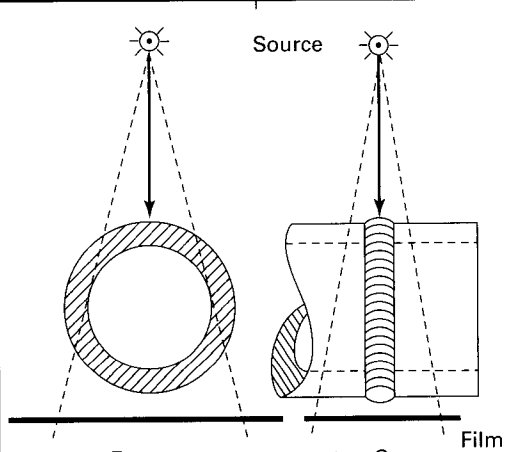
FIG. A-210-2 DOUBLE-WALL RADIOGRAPHIC TECHNIQUES

O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement		IQI		Location Marker Placement
			End View	Side View	Selection	Placement	
Any	Double-Wall: T-271.2(a) at Least 3 Exposures 120 deg. to Each Other for Complete Coverage	Single-Wall	 Exposure arrangement — D		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1 (b)(1)
Any	Double-Wall: T-271.2(a) at least 3 Exposures 120 deg. to Each Other for Complete Coverage	Single-Wall	 Exposure arrangement — E		T-276 and Table T-276	Source Side T-277.1(a) Film Side T-277.1(b)	Film Side T-275.1 (b)(1)
3½ in. (88 mm) or Less	Double-Wall T-271.2(b)(1) at Least 2 Exposures at 90 deg. to Each Other for Complete Coverage	Double-Wall (Ellipse): Read Offset Source Side and Film Side Images	 Exposure arrangement — F		T-276 and Table T-276	Source Side T-277.1(a)	Either Side T-275.2

(continued)

FIG. A-210-2 DOUBLE-WALL RADIOGRAPHIC TECHNIQUES (CONT'D)

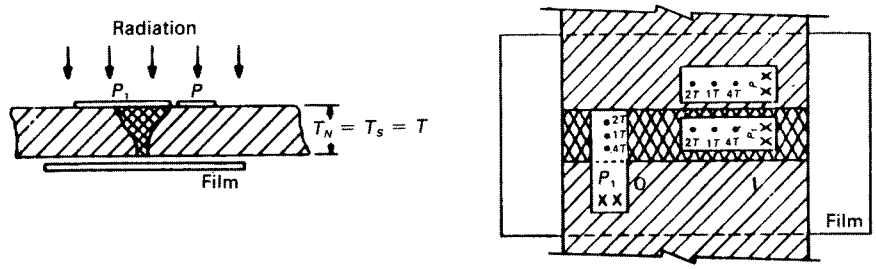
O.D.	Exposure Technique	Radiograph Viewing	Source-Weld-Film Arrangement		IQI		Location Marker Placement
			End View	Side View	Selection	Placement	
$3\frac{1}{2}$ in. (88 mm) or Less	Double-Wall: T-271.2(b)(2) at Least 3 Exposures at 60 deg. or 120 deg. to Each Other for Complete Coverage	Double-Wall: Read Super-imposed Source Side and Film Side Images	 Exposure arrangement — G		T-276 and Table T-276	Source Side T-277.1(a)	Either Side T-275.2

ARTICLE 2
NONMANDATORY APPENDIX

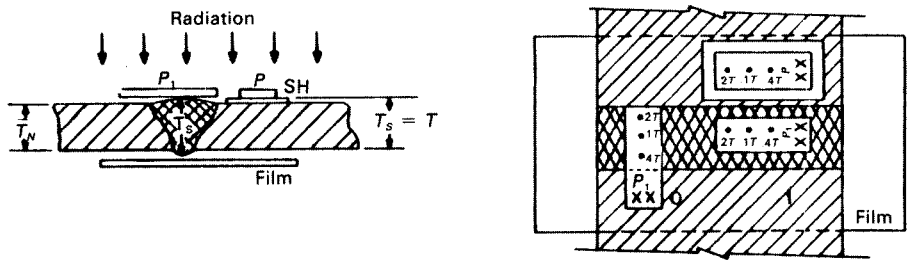
APPENDIX C — HOLE-TYPE IQI PLACEMENT SKETCHES FOR WELDS

C-210 SCOPE

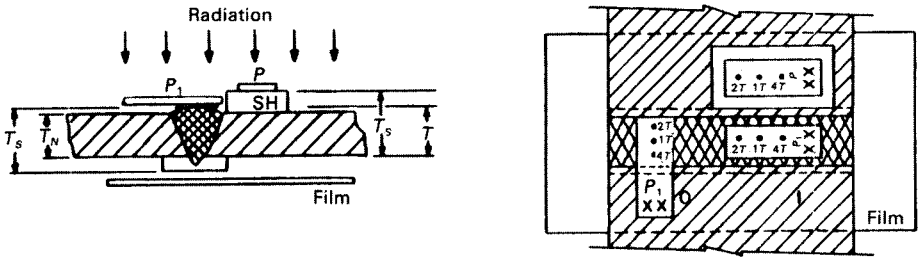
The figures in this Appendix demonstrate typical IQI (hole type) placement for welds. These sketches are tutorial to demonstrate suggested locations of IQIs and are not intended to cover all configurations or applications of production radiography. Other IQI locations may be used provided they comply with the requirements of Article 2. Wire IQIs shall be placed in accordance with the requirements of Article 2.



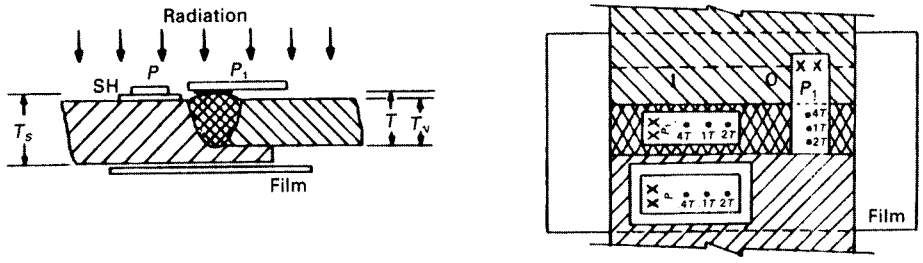
(a) Single Wall, No Reinforcement, No Back-Up Strip



(b) Single Wall, Weld Reinforcement, No Back-Up Strip



(c) Single Wall, Weld Reinforcement, Back-Up Strip

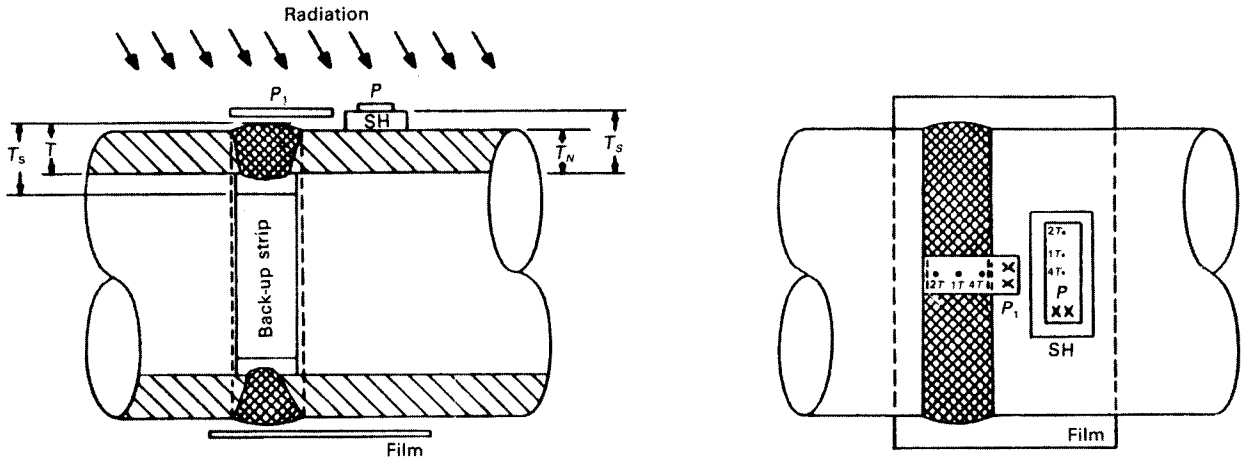


(d) Single Wall, Integral Backing Ring, Weld Reinforcement

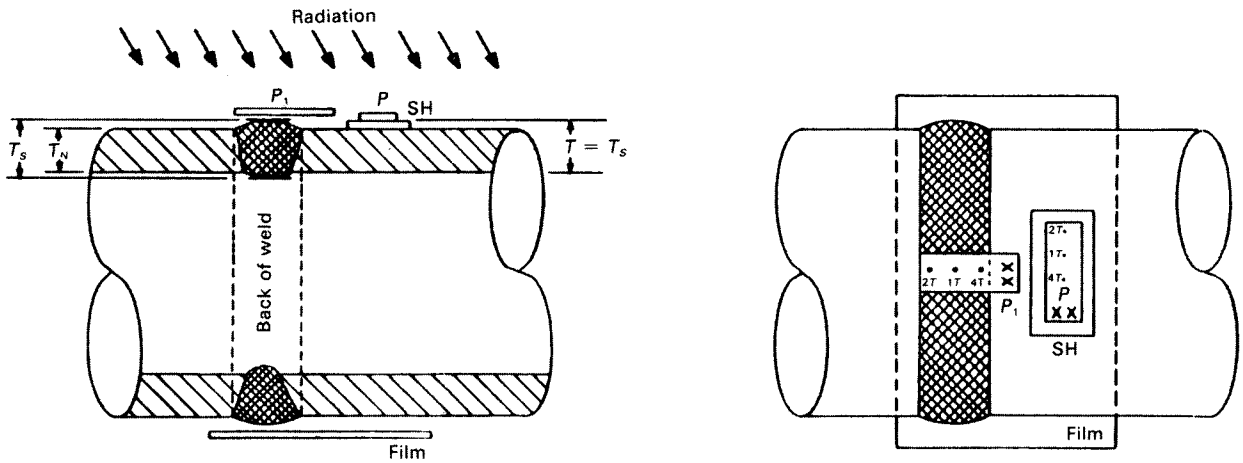
GENERAL NOTE:
P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

LEGEND:
P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-1 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS



(a) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and Back-Up Strip



(b) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and No Back-Up Strip

GENERAL NOTES:

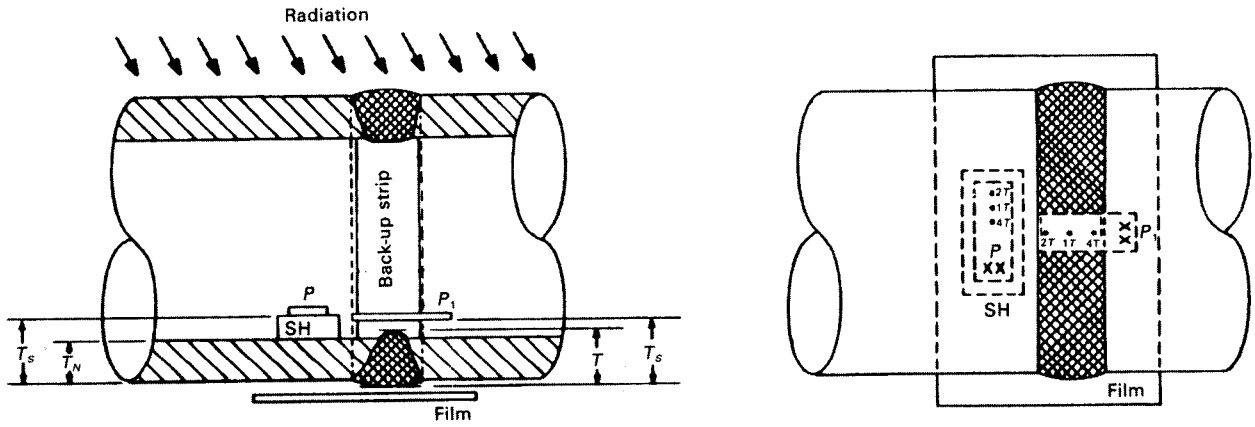
(a) P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

(b) IQI is based on the single-wall thickness plus reinforcement.

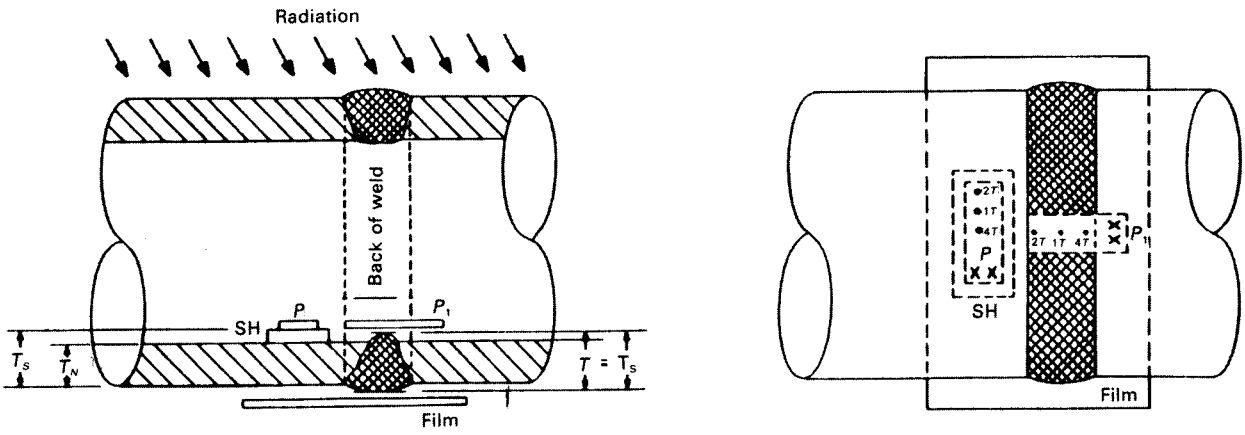
LEGEND:

P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-2 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS



(a) Double-Wall Technique, Single-Wall Viewing, Back-Up Strip

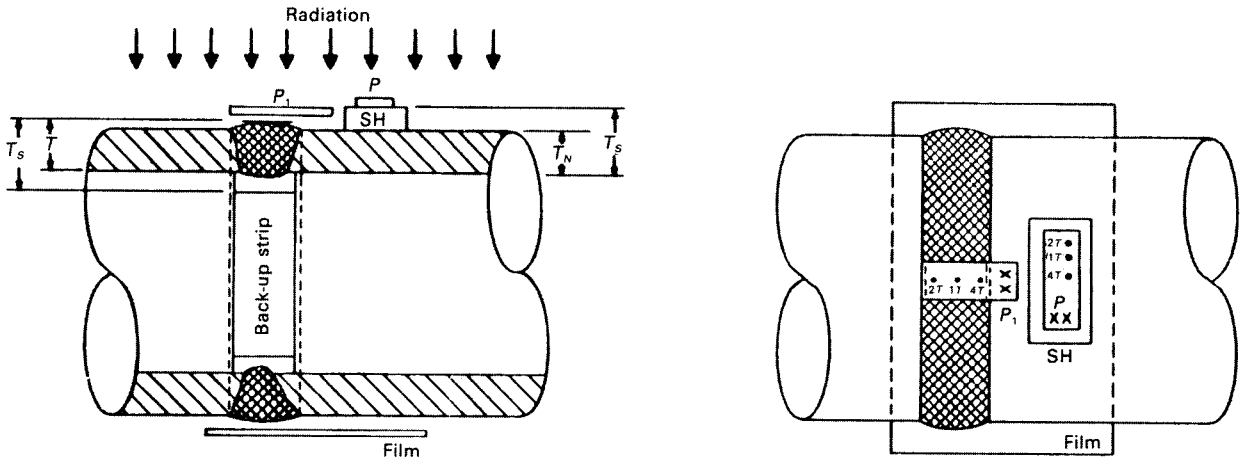


(b) Double-Wall Technique, Single-Wall Viewing, Wall Reinforcement, No Back-Up Strip

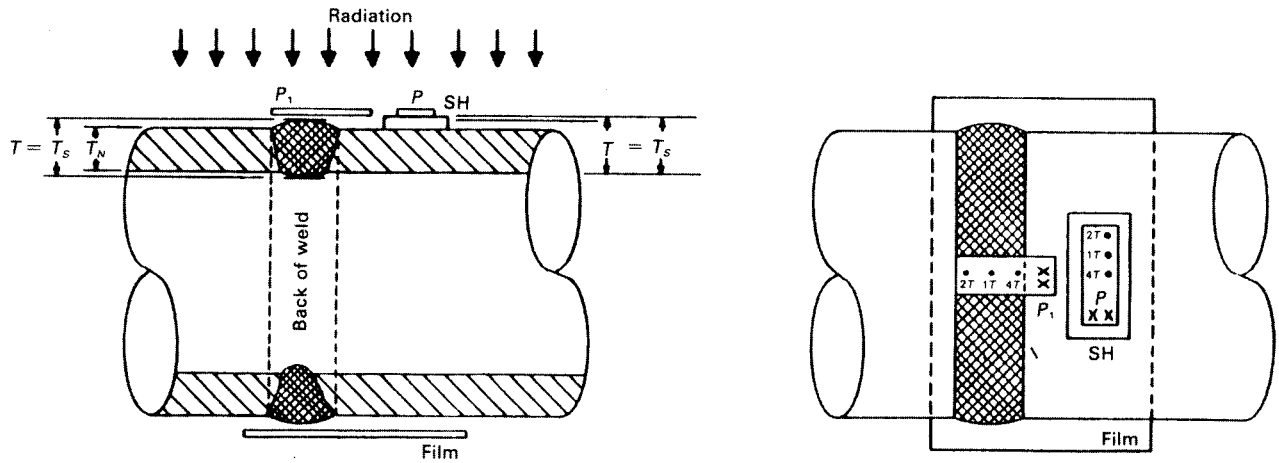
GENERAL NOTE:
P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

LEGEND:
P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-3 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS



(a) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and Back-Up Strip



(b) Double-Wall Technique, Double-Wall Viewing, With Weld Reinforcement and No Back-Up Strip

GENERAL NOTES:

(a) P and P_1 are suggested placements of IQIs and are not intended to cover all geometric configurations or applications of production radiography.

(b) IQI is based on the single-wall thickness plus reinforcement.

LEGEND:

P = IQI placement
P_1 = alternate IQI placement
SH = shim
T = weld thickness upon which the IQI is based
T_N = nominal wall thickness
T_S = total thickness including backing strip and/or reinforcement when not removed

FIG. C-210-4 SIDE AND TOP VIEWS OF HOLE-TYPE IQI PLACEMENTS

ARTICLE 2
NONMANDATORY APPENDIX

APPENDIX D — NUMBER OF IQIs (SPECIAL CASES)

D-210 SCOPE

The figures in this Appendix illustrate examples of the number and placement of IQIs that may be used in the special cases described in T-277.2(b). These figures are not intended to cover all configurations or applications of production radiography.

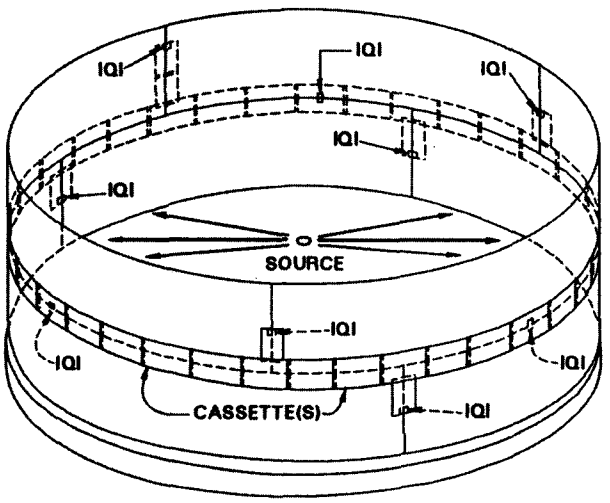


FIG. D-210-1 COMPLETE CIRCUMFERENCE CYLINDRICAL COMPONENT
[T-277.2(b)(1)(a) & T-277.2(b)(3)]

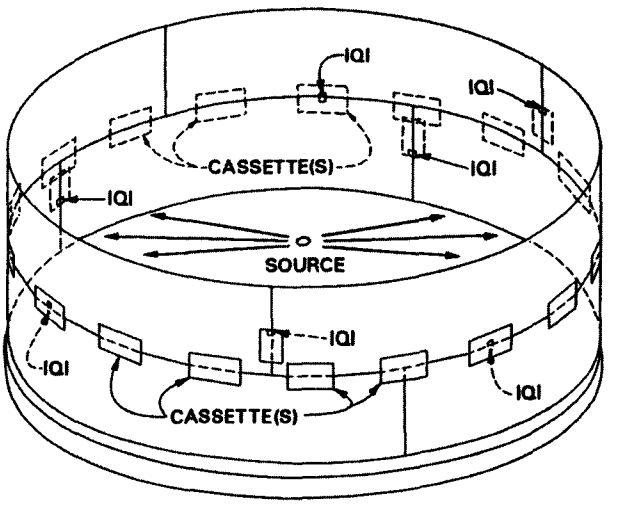


FIG. D-210-2 SECTION OF CIRCUMFERENCE 240 deg. OR MORE CYLINDRICAL COMPONENT (EXAMPLE IS ALTERNATE INTERVALS)
[T-277.2(b)(1)(b) & T-277.2(b)(3)]

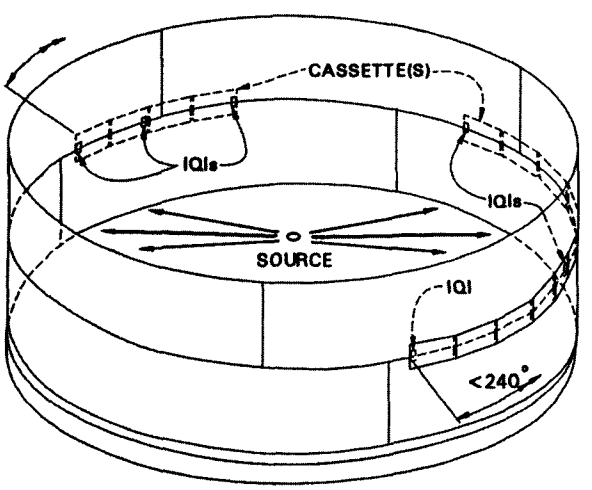


FIG. D-210-3 SECTION(S) OF CIRCUMFERENCE LESS THAN 240 deg. CYLINDRICAL COMPONENT
[T-277.2(b)(2)(b)]

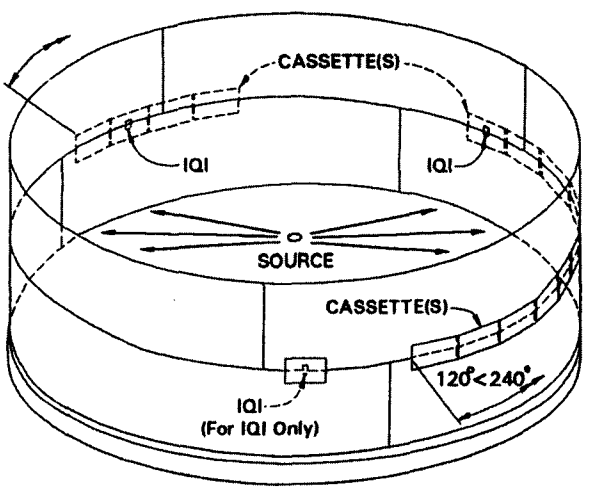
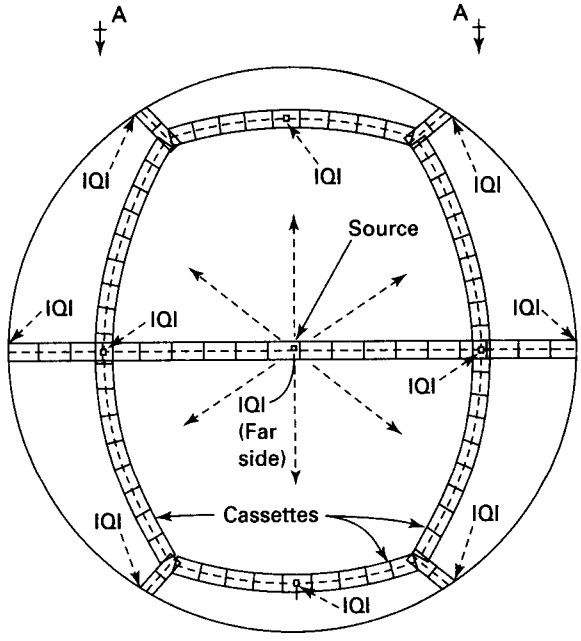


FIG. D-210-4 SECTION(S) OF CIRCUMFERENCE EQUAL TO OR MORE THAN 120 deg. AND LESS THAN 240 deg. CYLINDRICAL COMPONENT
[T-277.2(b)(2)(b) OPTION]



A06 FIG. D-210-5 COMPLETE CIRCUMFERENTIAL WELDS SPHERICAL COMPONENT
[T-277.2(b)(4)(a) & T-277.2(b)(6)]

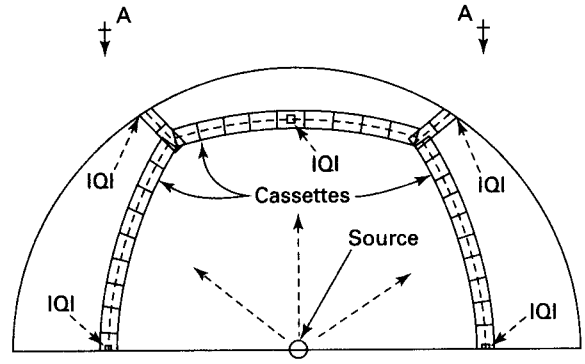


FIG. D-210-6 WELDS IN SEGMENTS OF SPHERICAL COMPONENT A06
[T-277.2(b)(5) & T-277.2(b)(5)(b) & T-277.2(b)(6)]

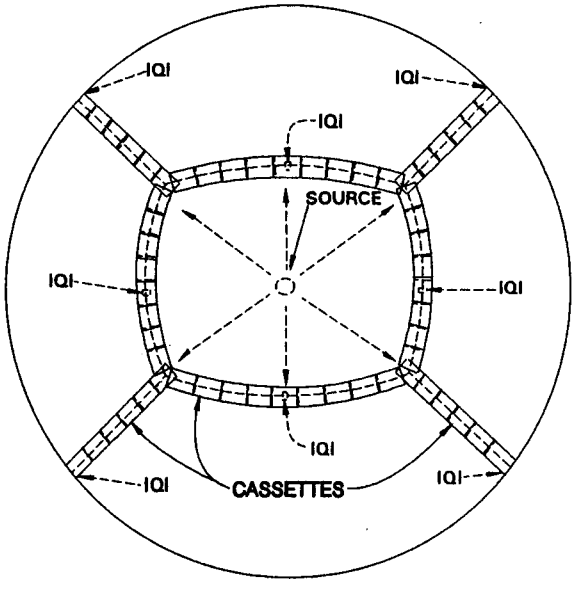
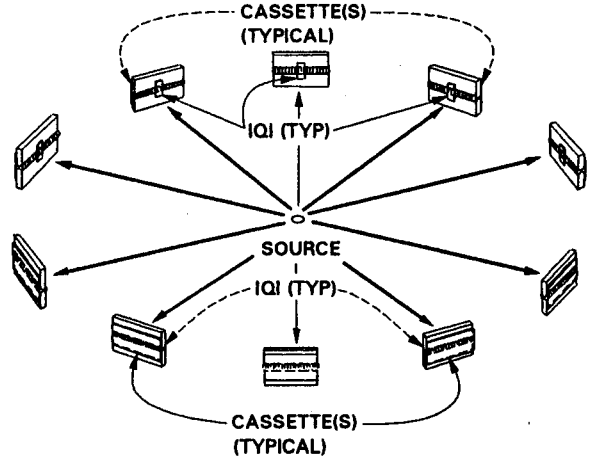


FIG. D-210-7 PLAN VIEW A-A



Note: Special Cases IQI Locations are Typical in All Figures.

FIG. D-210-8 ARRAY OF OBJECTS IN A CIRCLE A05
[T-277.2(b)(8)]

ARTICLE 4
ULTRASONIC EXAMINATION METHODS FOR WELDS

T-410 SCOPE

This Article provides or references requirements for weld examinations, which are to be used in selecting and developing ultrasonic examination procedures when examination to any part of this Article is a requirement of a referencing Code Section. These procedures are to be used for the ultrasonic examination of welds and the dimensioning of indications for comparison with acceptance standards when required by the referencing Code Section; the referencing Code Section shall be consulted for specific requirements for the following:

(*a*) personnel qualification/certification requirements

(*b*) procedure requirements/demonstration, qualification, acceptance

(*c*) examination system characteristics

(*d*) retention and control of calibration blocks

(*e*) extent of examination and/or volume to be scanned

(*f*) acceptance standards

(*g*) retention of records

(*h*) report requirements

Definitions of terms used in this Article are contained in Mandatory Appendix III of Article 5.

T-420 GENERAL

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The requirements of this Article shall be used together with Article 1, General Requirements. Refer to T-451 for special provisions for coarse grain materials and welds. Refer to T-452 for special provisions for computerized imaging techniques.

T-421 Written Procedure Requirements

T-421.1 Requirements. Ultrasonic examination shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements listed in Table T-421. The written procedure shall establish a single value, or range of values, for each requirement.

T-421.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-421 identified as an *essential variable* from the specified value, or range of values, shall require requalification of the written procedure. A change of a requirement identified as a *nonessential variable* from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

T-430 EQUIPMENT

T-431 Instrument Requirements

04

A pulse-echo-type of ultrasonic instrument shall be used. The instrument shall be capable of operation at frequencies over the range of at least 1 MHz to 5 MHz and shall be equipped with a stepped gain control in units of 2.0 dB or less. If the instrument has a damping control, it may be used if it does not reduce the sensitivity of the examination. The reject control shall be in the "off" position for all examinations, unless it can be demonstrated that it does not affect the linearity of the examination.

The instrument, when required because of the technique being used, shall have both send and receive jacks for operation of dual search units or a single search unit with send and receive transducers.

T-432 Search Units

T-432.1 General. The nominal frequency shall be from 1 MHz to 5 MHz unless variables, such as production material grain structure, require the use of other frequencies to assure adequate penetration or better resolution. Search units with contoured contact wedges may be used to aid ultrasonic coupling.

TABLE T-421 04
REQUIREMENTS OF AN ULTRASONIC EXAMINATION PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Weld configurations to be examined, including thickness dimensions and base material product form (pipe, plate, etc.)	X	
The surfaces from which the examination shall be performed	X	
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	
Angle(s) and mode(s) of wave propagation in the material	X	
Search unit type(s), frequency(ies), and element size(s)/shape(s)	X	
Special search units, wedges, shoes, or saddles, when used	X	
Ultrasonic instrument(s)	X	
Calibration [calibration block(s) and technique(s)]	X	
Directions and extent of scanning	X	
Scanning (manual vs. automatic)	X	
Method for discriminating geometric from flaw indications	X	
Method for sizing indications	X	
Computer enhanced data acquisition, when used	X	
Scan overlap (decrease only)	X	
Personnel performance requirements, when required	X	
Personnel qualification requirements		X
Surface condition (examination surface, calibration block)		X
Couplant: brand name or type		X
Automatic alarm and/or recording equipment, when applicable		X
Records, including minimum calibration data to be recorded (e.g., instrument settings)		X

T-432.2 Cladding—Search Units for Technique One.[1] Dual element search units using an angled pitch-catch technique shall be used. The included angle between the beam paths shall be such that the effective focal spot of the search unit is centered in the area of interest.

T-433 Couplant

T-433.1 General. The couplant, including additives, shall not be detrimental to the material being examined.

T-433.2 Control of Contaminants

(a) Couplants used on nickel base alloys shall not contain more than 250 ppm of sulfur.

(b) Couplants used on austenitic stainless steel or titanium shall not contain more than 250 ppm of halides (chlorides plus fluorides).

T-434 Calibration Blocks

T-434.1 General

A06 **T-434.1.1 Reflectors.** Specified reflectors (i.e., side drilled holes, flat bottom holes, notches, etc.) shall be used to establish primary reference responses of the equipment. An alternative reflector(s) may be used provided that the alternative reflector(s) produces a sensitivity equal to or greater than the specified reflector(s) (e.g., side drilled holes in lieu of notches, flat bottom holes in lieu of side drilled holes).

T-434.1.2 Material. The material from which the block is fabricated shall be of the same product form, and material specification or equivalent P-Number grouping as one of the materials being examined. For the purposes of this paragrpah, P-Nos. 1, 3, 4, and 5 materials are considered equivalent.

T-434.1.3 Quality. Prior to fabrication, the block material shall be completely examined with a straight beam search unit. Areas that contain an indication exceeding the remaining back-wall reflection shall be excluded from the beam paths required to reach the various calibration reflectors.

T-434.1.4 Cladding. When the component material is clad, the block shall be clad by the same welding procedure as the production part. It is desirable to have component materials which have been clad before the drop outs or prolongations are removed. When the cladding is deposited using an automatic welding process, and, if due to block size, the automatic welding process is impractical, deposition of clad may be by the manual method.

T-434.1.5 Heat Treatment. The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade. If the calibration block contains welds other than cladding, and the component weld at the time of the examination has been heat treated, the block shall receive the same heat treatment.

[1] See paragraph T-473 for cladding techniques.

T-434.1.6 Surface Finish. The finish on the scanning surfaces of the block shall be reprentative of the scanning surface finishes on the component to be examined.

T-434.1.7 Block Curvature (Except for Piping)

T-434.1.7.1 Materials With Diameters Greater Than 20 in. (500 mm). For examinations in materials where the examination surface diameter is greater than 20 in. (500 mm), a block of essentially the same curvature, or alternatively, a flat basic calibration block, may be used.

T-434.1.7.2 Materials With Diameters 20 in. (500 mm) and Less. For examinations in materials where the examination surface diameter is equal to or less than 20 in. (500 mm), a curved block shall be used. Except where otherwise stated in this Article, a single curved basic calibration block may be used for examinations in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. For example, an 8 in (200 mm) diameter block may be used to calibrate for examinations on surfaces in the range of curvature from 7.2 in. to 12 in. (180 mm to 300 mm) in diameter. The curvature range from 0.94 in. to 20 in. (24 mm to 500 mm) in diameter requires 6 curved blocks as shown in Fig. T-434.1.7.2 for any thickness range.

T-434.1.7.3 Alternative for Convex Surface. As an alternative to the requirements in T-434.1.7.1 when examining from the convex surface by the straight beam contact technique, Appendix G may be used.

T-434.2 Non-Piping Calibration Blocks

T-434.2.1 Basic Calibration Block. The basic calibration block configuration and reflectors shall be as shown in Fig. T-434.2.1. The block size and reflector locations shall be adequate to perform calibrations for the beam angles used.

04 **T-434.2.2 Block Thickness.** When two or more base material thicknesses are involved, the calibration block thickness shall be determined by the average thickness of the weld. Alternatively, a calibration block having the greater base material thickness may be used provided the reference reflector size is based upon the average or smaller weld thickness.

04 **T-434.2.3 Block Range of Use.** When the block thickness ± 1 in. (25 mm) spans two weld thickness ranges as shown in Fig. T-434.2.1, the block's use shall be acceptable in those portions of each thickness range covered by 1 in. (25 mm) of the calibration block's thickness. As an example, a calibration block with a thickness of 1½ in. (38 mm) could be used for weld thicknesses of 0.5 in. (13 mm) to 2.5 in. (64 mm).

T-434.2.4 Alternate Block. Alternatively, the block may be constructed as shown Nonmandatory Appendix J, Fig. J-431.

T-434.3 Piping Calibration Blocks. The basic calibration block configuration and reflectors shall be as shown in Fig. T-434.3. The basic calibration block shall be a section of pipe of the same nominal size and schedule. The block size and reflector locations shall be adequate to perform calibration for the beam angles used.

T-434.4 Cladding Calibration Blocks[2]

T-434.4.1 Calibration Block for Technique One. The basic calibration block configuration and reflectors shall be as shown in Fig. T-434.4.1. Either a side-drilled hole or a flat bottom hole may be used. The thickness of the weld overaly shall be at least as thick as that to be examined. The thickness of the base material shall be at least twice the thickness of the cladding.

T-434.4.2 Alternate Calibration Blocks for Technique One. Alternately, calibration blocks as shown in Fig. T-434.4.2.1 or T-434.4.2.2 may be used. The thickness of the weld overlay shall be at least as thick as that to be examined. The thickness of the base material shall be at least twice the thickness of the cladding.

T-434.4.3 Calibration Block for Technique Two. The basic calibration block configuration and reflectors shall be as shown in Fig. T-434.4.3. A flat bottom hole drilled to the weld metal overlay interface shall be used. This hole may be drilled from the base material or weld overlay side. The thickness of the weld overlay shall be at least as thick as that to be examined. The thickness of the base material shall be within 1 in. (25 mm) of the calibration block thickness when the examination is performed from the base material surface. The thickness of the base material on the calibration block shall be at least twice the thickness of the cladding when the examination is performed from the clad surface.

T-440 MISCELLANEOUS REQUIREMENTS

T-441 Identification of Weld Examination Areas

(a) Weld Locations. Weld locations and their identification shall be recorded on a weld map or in an identification plan.

(b) Marking. If welds are to be permanently marked, low stress stamps and/or vibratooling may be used. Markings applied after final stress relief of the component shall not be any deeper than 3/64 in. (1.2 mm).

[2] See paragraph T-465, Calibration for Cladding.

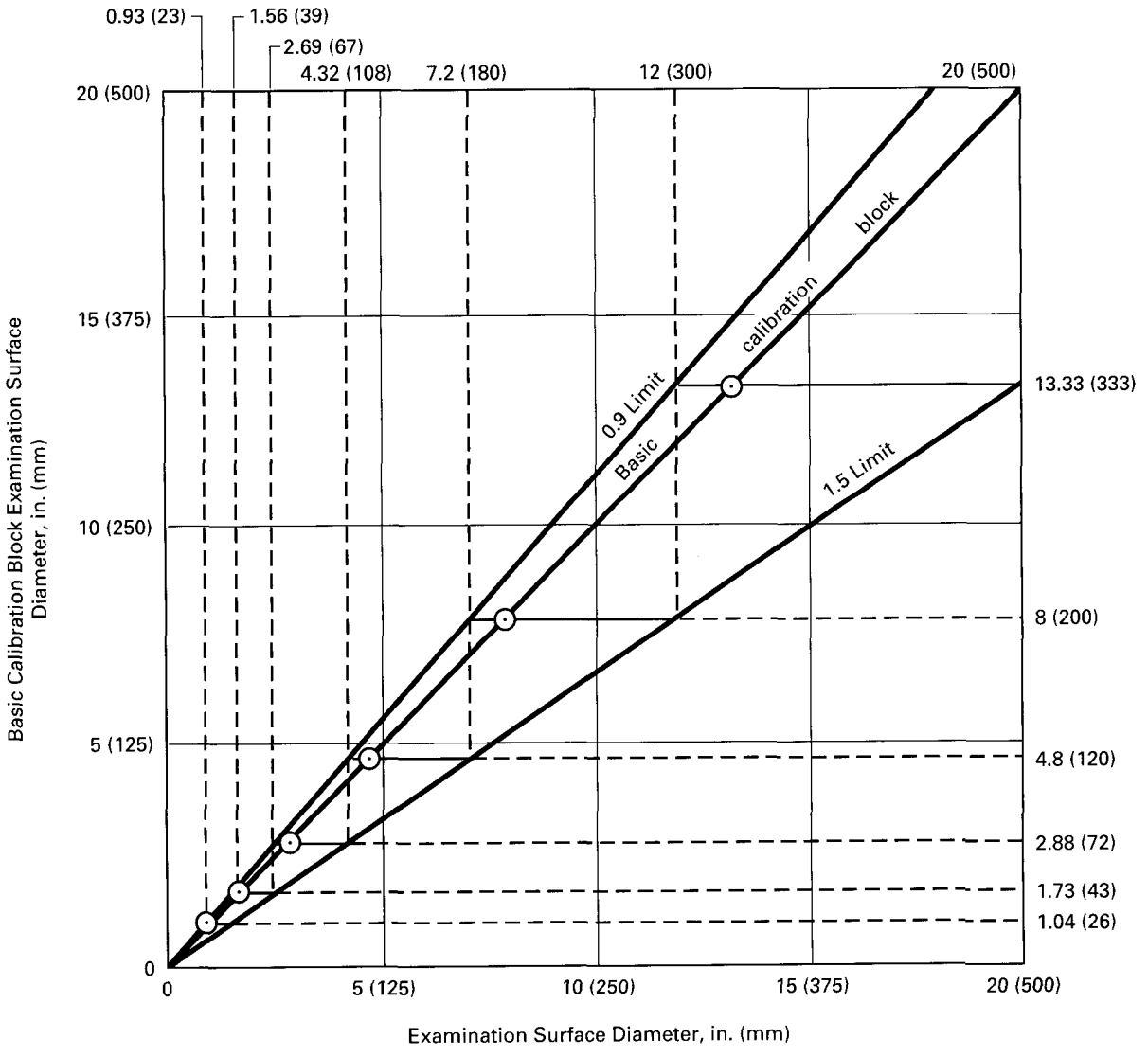


FIG. T-434.1.7.2 RATIO LIMITS FOR CURVED SURFACES

(c) Reference System. Each weld shall be located and identified by a system of reference points. The system shall permit identification of each weld center line and designation of regular intervals along the length of the weld. A general system for layout of vessel welds is described in Nonmandatory Appendix A; however, a different system may be utilized provided it meets the above requirements.

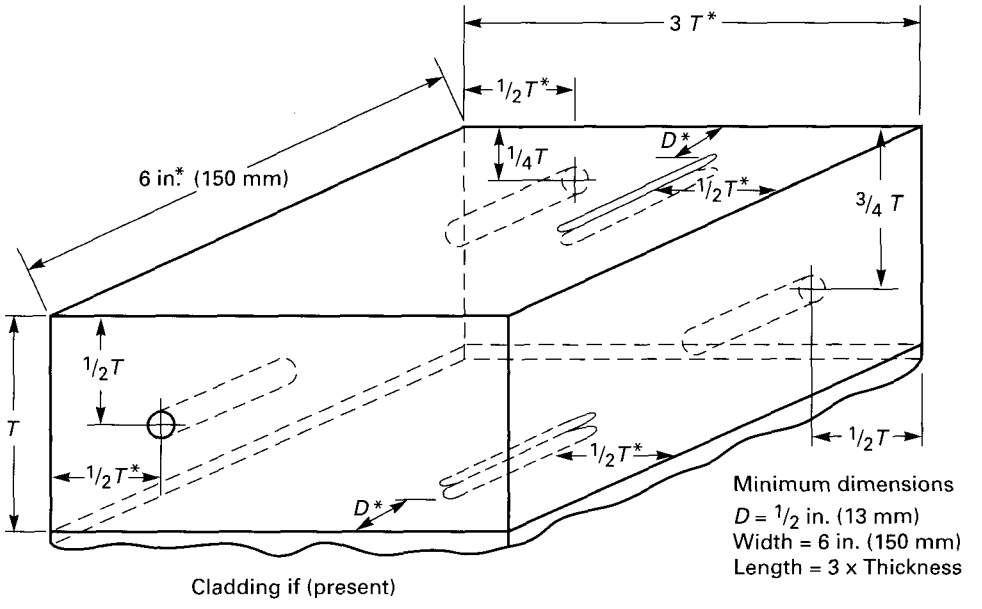
04 T-450 TECHNIQUES

The techniques described in this Article are intended for applications where either single or dual element search units are used to produce:

(a) normal incident longitudinal wave beams for what are generally termed ***straight beam*** examinations or

(b) angle beam longitudinal waves, where both refracted longitudinal and shear waves are present in the material under examination. When used for thickness measurement or clad examination, these examinations are generally considered to be straight beam examinations. When used for weld examinations, they are generally termed ***angle beam*** examinations or

(c) angle beam shear waves, where incident angles in wedges produce only refracted shear waves in the material under examination are generally termed ***angle beam*** examinations.



Weld Thickness (t), in. (mm)	Calibration Block Thickness (T), in. (mm)	Hole Diameter, in. (mm)
Up to 1 (25)	3/4 (19) or t	3/32 (2.5)
Over 1 (25) through 2 (50)	1 1/2 (38) or t	1/8 (3)
Over 2 (50) through 4 (100)	3 (75) or t	3/16 (5)
Over 4 (100)	$t \pm 1$ (25)	[Note (1)]

Notch Dimensions, in. (mm)
Notch depth = 2% T
Notch width = 1/4 (6) max.
Notch length = 1 (25) min.

* Minimum dimension.

GENERAL NOTES:

(a) Holes shall be drilled and reamed 1.5 in. (38 mm) deep minimum, essentially parallel to the examination surface.

(b) For components equal to or less than 20 in. (500 mm) in diameter, calibration block diameter shall meet the requirements of T-434.1.7.2. Two sets of calibration reflectors (holes, notches) oriented 90 deg from each other shall be used. Alternatively, two curved calibration blocks may be used.

(c) The tolerance for hole diameter shall be ± 1/32 in. (0.8 mm). The tolerance for hole location through the calibration block thickness (i.e., distance from the examination surface) shall be ± 1/8 in. (3 mm).

(d) For blocks less than 3/4 in. (19 mm) in thickness, only the 1/2 T side-drilled hole and surface notches are required.

(e) All holes may be located on the same face (side) of the calibration block, provided care is exercised to locate all the reflectors (holes, notches) to prevent one reflector from affecting the indication from another reflector during calibration. Notches may also be in the same plane as the inline holes (See Appendix J, Fig. J-431). As in Fig. J-431, a sufficient number of holes shall be provided for both angle and straight beam calibrations at the 1/4 T, 1/2 T, and 3/4 T depths.

(f) Minimum notch depth shall be 1.6% T and maximum notch depth shall be 2.2% T plus the thickness of cladding, if present.

(g) Maximum notch width is not critical. Notches may be made by EDM or with end mills up to 1/4 in. (6.4 mm) in diameter.

NOTE:

(1) For each increase in weld thickness of 2 in. (50 mm) or fraction thereof over 4 in. (100 mm), the hole diameter shall increase 1/16 in. (1.5 mm).

04 A05

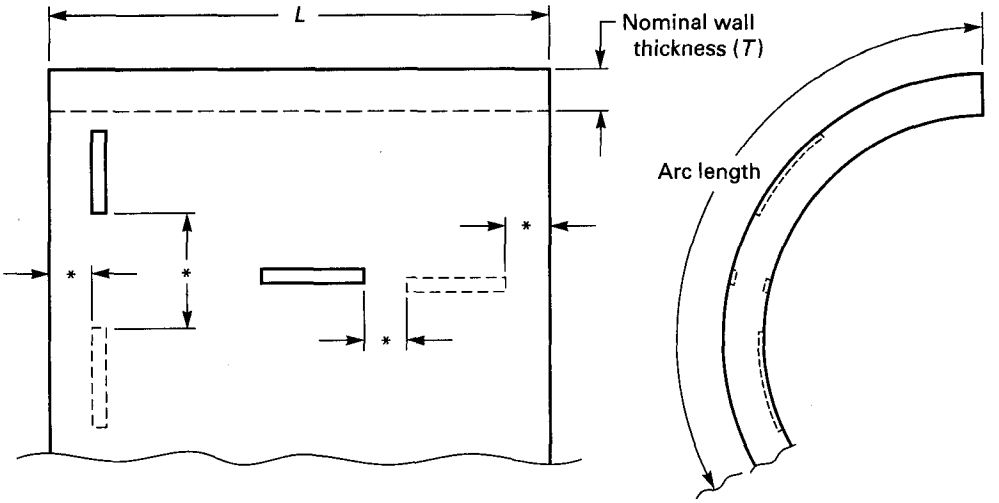
FIG. T-434.2.1 NON-PIPING CALIBRATION BLOCKS

Contact or immersion techniques may be used. Base materials and/or welds with metallurgical structures producing variable attenuations may require that longitudinal angle beams are used instead of shear waves. Additionally, computerized imaging techniques may enhance the detectability and evaluation of indications.

Other techniques or technology which can be demonstrated to produce equivalent or better examination sensitivity and detectability using search units with more than two transducer elements may be used. The demonstration shall be in accordance with Article 1, T-150(a).

T-451 Coarse Grain Materials

Ultrasonic examinations of high alloy steels and high nickel alloy weld deposits and dissimilar metal welds between carbon steels and high alloy steels and high nickel alloys are usually more difficult than ferritic weld



* Notches shall be located not closer than T or 1 in. (25 mm), whichever is greater, to any block edge or to other notches.

GENERAL NOTES:

(a) The minimum calibration block length (L) shall be 8 in. (200 mm) or 8T, whichever is greater.

(b) For OD 4 in. (100 mm) or less, the minimum arc length shall be 270 deg. For OD greater than 4 in. (100 mm), the minimum arc length shall be 8 in. (200 mm) or 3T, whichever is greater.

(c) Notch depths shall be from 8% T minimum to 11% T maximum. Notch widths shall be $\frac{1}{4}$ in. (6 mm) maximum. Notch lengths shall be 1 in. (25 mm) minimum.

(d) Maximum notch width is not critical. Notches may be made with EDM or with end mills up to $\frac{1}{4}$ in. (6 mm) in diameter.

(e) Notch lengths shall be sufficient to provide for calibration with a minimum 3 to 1 signal-to-noise ratio.

FIG. T-434.3 CALIBRATION BLOCK FOR PIPE 04

examinations. Difficulties with ultrasonic examinations can be caused by an inherent coarse-grained and/or a directionally-oriented structure, which can cause marked variations in attenuation, reflection, and refraction at grain boundaries and velocity changes within the grains. It usually is necessary to modify and/or supplement the provisions of this Article in accordance with T-150(a) when examining such welds in these materials. Additional items, which may be necessary, are weld mockups with reference reflectors in the weld deposit and single or dual element angle beam longitudinal wave transducers.

T-452 Computerized Imaging Techniques

The major attribute of Computerized Imaging Techniques (CITs) is their effectiveness when used to characterize and evaluate indications; however, CITs may also be used to perform the basic scanning functions required for flaw detection. Computer-processed data analysis and display techniques are used in conjunction with automatic or semi-automatic scanning mechanisms to produce two and three-dimensional images of flaws, which provides an enhanced capability for examining critical components and structures. Computer processes may be used to quantitatively evaluate the type, size, shape, location, and orientation of flaws detected by ultrasonic examination or other NDE methods. Descriptions for some CITs that may be used are provided in Nonmandatory Appendix E.

T-460 CALIBRATION

T-461 Instrument Linearity Checks A06

The requirements of T-461.1 and T-461.2 shall be met at intervals not to exceed three months for analog type instruments and one year for digital type instruments, or prior to first use thereafter.

T-461.1 Screen Height Linearity. The ultrasonic instrument's screen height linearity shall be evaluated in accordance with Mandatory Appendix I.

T-461.2 Amplitude Control Linearity. The ultrasonic instrument's amplitude control linearity shall be evaluated in accordance with Mandatory Appendix II.

T-462 General Calibration Requirements

T-462.1 Ultrasonic System. Calibrations shall include the complete ultrasonic system and shall be per-

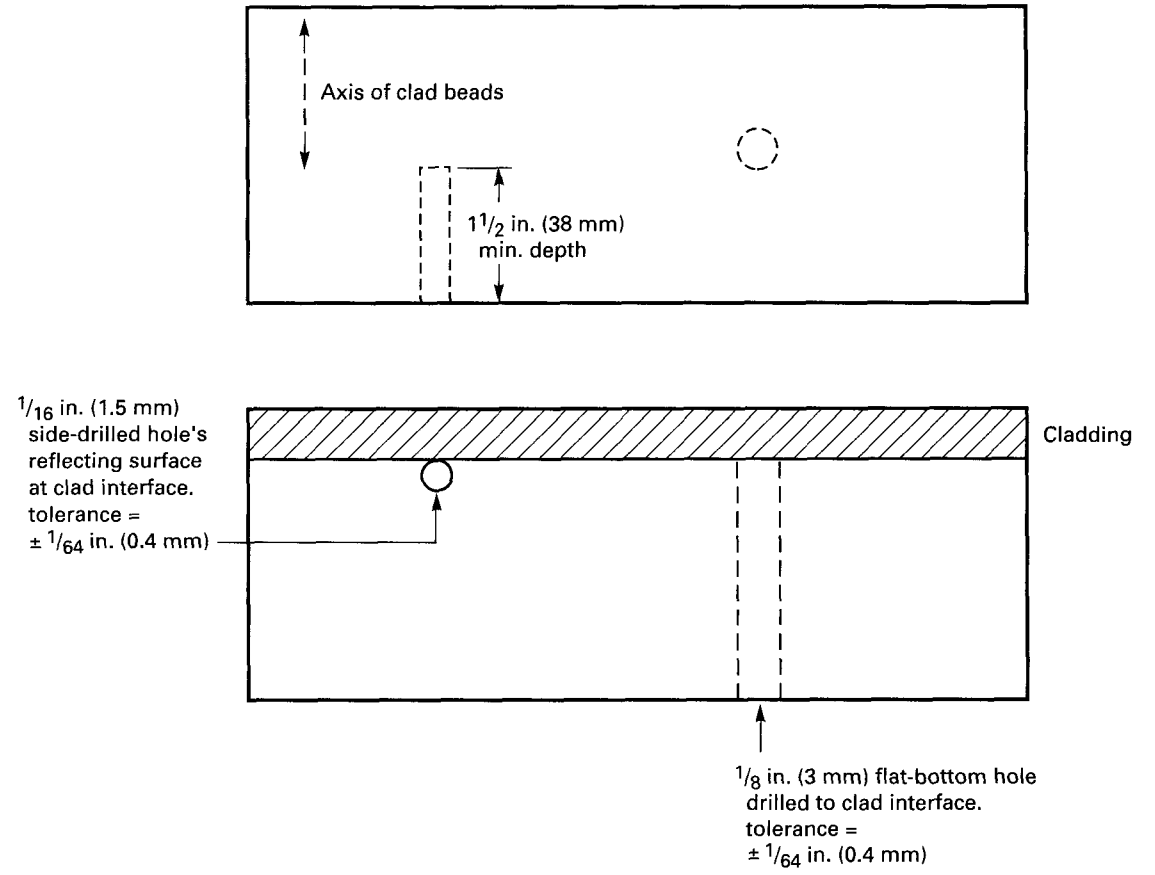


FIG. T-434.4.1 CALIBRATION BLOCK FOR TECHNIQUE ONE

formed prior to use of the system in the thickness range under examination.

T-462.2 Calibration Surface. Calibrations shall be performed from the surface (clad or unclad; convex or concave) corresponding to the surface of the component from which the examination will be performed.

T-462.3 Couplant. The same couplant to be used during the examination shall be used for calibration.

T-462.4 Contact Wedges. The same contact wedges to be used during the examination shall be used for calibration.

T-462.5 Instrument Controls. Any control which affects instrument linearity (e.g., filters, reject, or clipping) shall be in the same position for calibration, calibration checks, instrument linearity checks, and examination.

T-462.6 Temperature. For contact examination, the temperature differential between the calibration block and examination surfaces shall be within 25°F (14°C). For immersion examination, the couplant temperature for calibration shall be within 25°F (14°C) of the couplant temperature for examination.

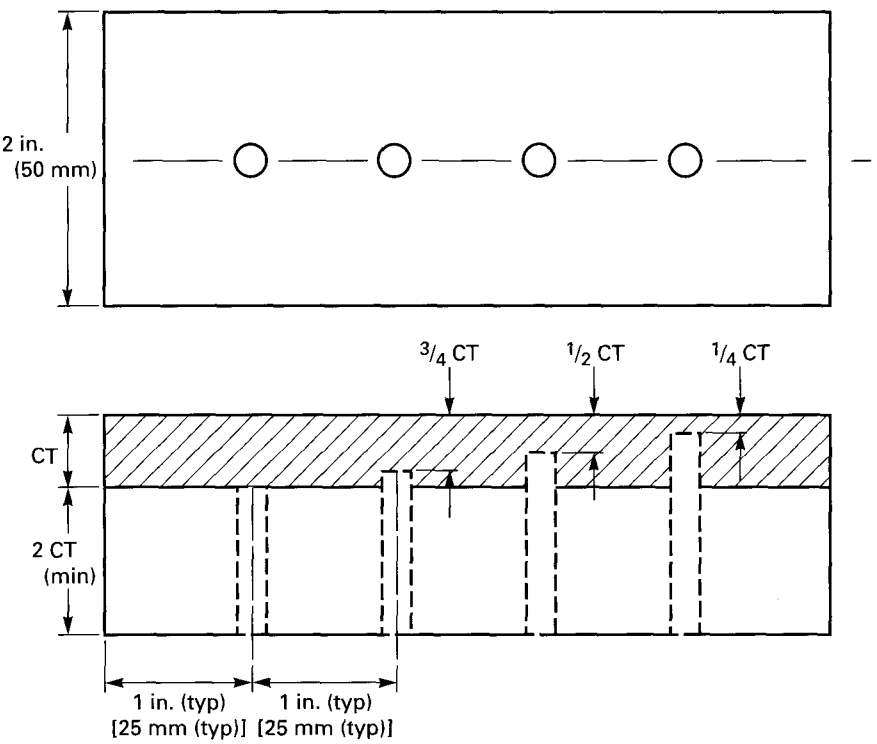
T-463 Calibration for Non-Piping

T-463.1 System Calibration for Distance Amplitude Techniques

T-463.1.1 Calibration Block(s). Calibrations shall be performed utilizing the calibration block shown in Fig. T-434.2.1.

T-463.1.2 Techniques. Nonmandatory Appendices B and C provide general techniques for both angle beam shear wave and straight beam calibrations. Other techniques may be used. 04

The angle beam shall be directed toward the calibration reflector that yields the maximum response in the area of interest. The gain control shall be set so that this response is 80% ± 5% of full screen height. This shall be the primary reference level. The search unit shall then be manipulated, without changing instrument settings, to obtain the maximum responses from the other calibration reflectors at their beam paths to generate the distance-amplitude correction (DAC) curve. These calibrations shall establish both the distance range calibration and the distance amplitude correction.



GENERAL NOTE: All flat-bottom holes are $\frac{1}{8}$ in. (3 mm) diameter. Tolerances for hole diameter and depth with respect to the clad side of the block are ± $\frac{1}{64}$ in. (0.4 mm).

FIG. T-434.4.2.1 ALTERNATE CALIBRATION BLOCK FOR TECHNIQUE ONE

04 A05 **T-463.1.3 Angle Beam Calibration.** As applicable, the calibration shall provide the following measurements (Nonmandatory Appendices B and M contain general techniques):

(a) distance range calibration;

(b) distance-amplitude;

(c) echo amplitude measurement from the surface notch in the basic calibration block.

When an electronic distance-amplitude correction device is used, the primary reference responses from the basic calibration block shall be equalized over the distance range to be employed in the examination. The response equalization line shall be at a screen height of 40% to 80% of full screen height.

04 **T-463.1.4 Straight Beam Calibration.** The calibration shall provide the following measurements (Nonmandatory Appendix C gives a general technique):

(a) distance range calibration; and

(b) distance-amplitude correction in the area of interest.

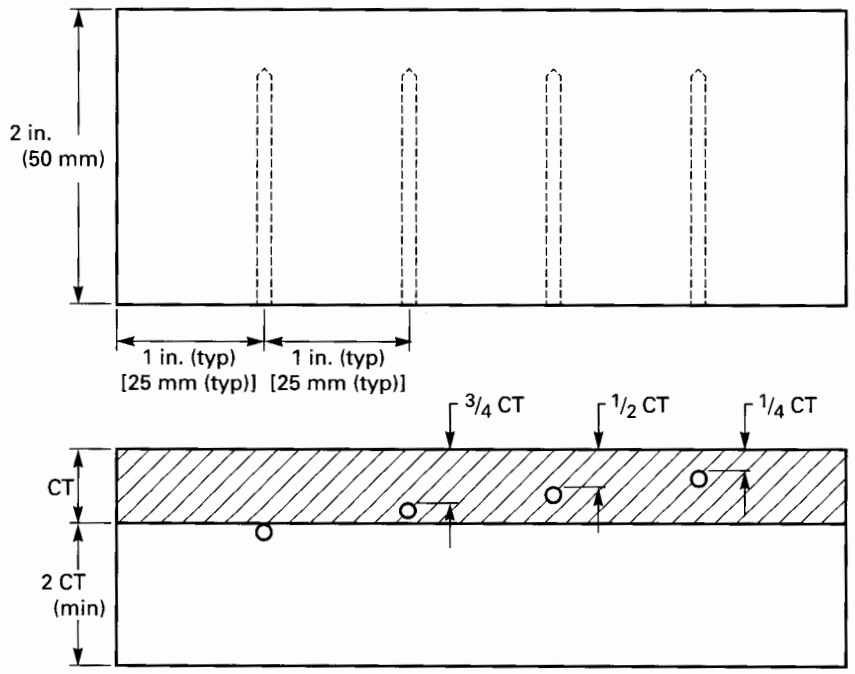
When an electronic distance-amplitude correction device is used, the primary reference responses from the basic calibration block shall be equalized over the distance range to be employed in the examination. The response equalization line shall be at a screen height of 40% to 80% of full screen height.

T-463.2 System Calibration for Non-Distance Amplitude Techniques. Calibration includes all those actions required to assure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system (whether displayed, recorded, or automatically processed) are repeated from examination to examination. Calibration may be by use of basic calibration blocks with artificial or discontinuity reflectors. Methods are provided in Nonmandatory Appendices B and C. Other methods of calibration may include sensitivity adjustment based on the examination material, etc.

T-464 Calibration for Piping

T-464.1 System Calibration for Distance Amplitude Techniques

T-464.1.1 Calibration Block(s). Calibrations shall be performed utilizing the calibration block shown in Fig. T-434.3.



GENERAL NOTE: All side-drilled holes are $\frac{1}{16}$ in. (1.5 mm) diameter. Holes location tolerance is ± $\frac{1}{64}$ in. (0.4 mm). All holes drilled to a minimum depth of 1.5 in. (38 mm).

FIG. T-434.4.2.2 ALTERNATE CALIBRATION BLOCK FOR TECHNIQUE ONE

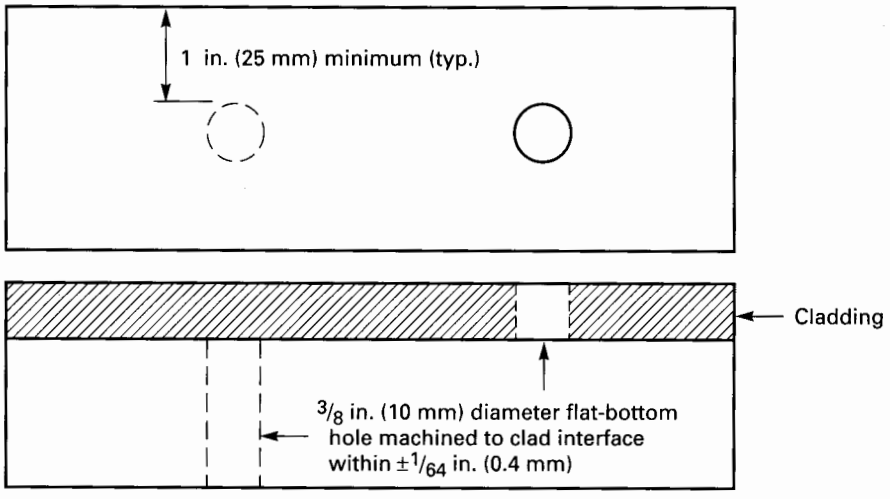


FIG. T-434.4.3 ALTERNATE CALIBRATION BLOCK FOR TECHNIQUE TWO

T-464.1.2 Angle Beam Calibration. The angle beam shall be directed toward the calibration reflector that yields the maximum response. The gain control shall be set so that this response is 80% ±5% of full screen height. This shall be the primary reference level. The search unit shall then be manipulated, without changing instrument settings, to obtain the maximum responses from the calibration reflectors at the distance increments necessary to generate a three-point distance-amplitude correction (DAC) curve. Separate calibrations shall be established for both the axial and circumferential notches. These calibrations shall establish both the distance range calibration and the distance amplitude correction.

04 A06 **T-464.1.3 Straight Beam Calibration.** When required, straight beam calibrations shall be performed to the requirements of Nonmandatory Appendix C using the side drilled hole alternate calibration reflectors of T-434.1.1. This calibration shall establish both the distance range calibration and the distance amplitude correction.

T-464.2 System Calibration for Non-Distance Amplitude Techniques. Calibration includes all those actions required to assure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system (whether displayed, recorded, or automatically processed) are repeated from examination to examination. Calibration may be by use of basic calibration blocks with artificial or discontinuity reflectors. Methods are provided in Nonmandatory Appendices B and C. Other methods of calibration may include sensitivity adjustment based on the examination material, etc.

T-465 Calibration for Cladding

T-465.1 Calibration for Technique One. Calibrations shall be performed utilizing the calibration block shown in Fig. T-434.4.1. The search unit shall be positioned for the maximum response from the calibration reflector. The gain control shall be set so that this response is 80% ±5% of full screen height. This shall be the primary reference level.

T-465.2 Calibration for Technique Two. Calibrations shall be performed utilizing the calibration block shown in Fig. T-434.4.3. The search unit shall be positioned for the maximum response of the first resolvable indication from the bottom of the calibration reflector. The gain shall be set so that this response is 80% ±5% of full screen height. This shall be the primary reference level.

T-465.3 Alternate Calibration for Technique One. Calibrations shall be performed utilizing the calibration blocks shown in Fig. T-434.4.2.1 or T-434.4.2.2. The calibration shall be performed as follows:

(a) The search unit shall be positioned for maximum response from the reflector, which gives the highest amplitude.

(b) The gain shall be set so that this response is 80% ±5% of full screen height. This shall be the primary reference level. Mark the peak of the indication on the screen.

(c) Without changing the instrument settings, position the search unit for maximum response from each of the other reflectors and mark their peaks on the screen.

(d) Connect the screen marks for each reflector to provide a DAC curve.

T-466 Calibration Confirmation

T-466.1 System Changes. When any part of the examination system is changed, a calibration check shall be made on the basic calibration block to verify that distance range points and sensitivity setting(s) satisfy the requirements of T-466.3.

T-466.2 Periodic Examination Checks. A calibration check on at least one of the basic reflectors in the basic calibration block or a check using a simulator shall be made at the finish of each examination or series of similar examinations, every 4 hr during the examination, and when examination personnel (except for automated equipment) are changed. The distance range points and sensitivity setting(s) recorded shall satisfy the requirements T-466.3.

T-466.2.1 Simulator Checks. Any simulator checks that are used shall be correlated with the original calibration on the basic calibration block during the original calibration. The simulator checks may use different types of calibration reflectors or blocks (such as IIW) and/or electronic simulation. However, the simulation used shall be identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be checked in one operation; however, for its check, the search unit shall be connected to the ultrasonic instrument and checked against a calibration reflector. Accuracy of the simulator checks shall be confirmed, using the basic calibration block, at the conclusion of each period of extended use, or every three months, whichever is less.

T-466.3 Confirmation Acceptance Values

T-466.3.1 Distance Range Points. If any distance range point has moved on the sweep line by more than

10% of the distance reading or 5% of full sweep, whichever is greater, correct the distance range calibration and note the correction in the examination record. All recorded indications since the last valid calibration or calibration check shall be reexamined and their values shall be changed on the data sheets or re-recorded.

T-466.3.2 Sensitivity Settings. If any sensitivity setting has changed by more than 20% or 2 dB of its amplitude, correct the sensitivity calibration and note the correction in the examination record. If the sensitivity setting has decreased, all data sheets since the last valid calibration check shall be marked void and the area covered by the voided data shall be reexamined. If the sensitivity setting has increased, all recorded indications since the last valid calibration or calibration check shall be reexamined and their values shall be changed on the data sheets or re-recorded.

T-470 EXAMINATION

T-471 General Examination Requirements

04 **T-471.1 Examination Coverage.** The volume to be scanned shall be examined by moving the search unit over the scanning surface so as to scan the entire examination volume for each required search unit.

(a) Each pass of the search unit shall overlap a minimum of 10% of the transducer (piezoelectric element) dimension parallel to the direction of scan indexing. As an alternative, if the sound beam dimension parallel to the direction of scan indexing is measured in accordance with Nonmandatory Appendix B, B-466, Beam Spread measurement rules, each pass of the search unit may provide overlap of the minimum beam dimension determined.

(b) Oscillation of the search unit is permitted if it can be demonstrated that overlapping coverage is provided.

T-471.2 Pulse Repetition Rate. The pulse repetition rate shall be small enough to assure that a signal from a reflector located at the maximum distance in the examination volume will arrive back at the search unit before the next pulse is placed on the transducer.

T-471.3 Rate of Search Unit Movement. The rate of search unit movement (scanning speed) shall not exceed 6 in./s (150 mm/s), unless:

(a) the ultrasonic instrument pulse repetition rate is sufficient to pulse the search unit at least six times within the time necessary to move one-half the transducer (piezoelectric element) dimension parallel to the direction of the scan at maximum scanning speed; or,

(b) a dynamic calibration is performed on multiple reflectors, which are within ±2 dB of a static calibration and the pulse repetition rate meets the requirements of T-471.2.

T-471.4 Scanning Sensitivity Level

T-471.4.1 Distance Amplitude Techniques. The 04 scanning sensitivity level shall be set a minimum[3] of 6 dB higher than the reference level gain setting.

T-471.4.2 Non-Distance Amplitude Techniques. The level of gain used for scanning shall be appropriate for the configuration being examined and shall be capable of detecting the calibration reflectors at the maximum scanning speed.

T-471.5 Surface Preparation. When the base material or weld surface interferes with the examination, the base material or weld shall be prepared as needed to permit the examination.

T-472 Weld Joint Distance Amplitude Technique

When the referencing Code Section specifies a distance amplitude technique, weld joints shall be scanned with an angle beam search unit in both parallel and transverse directions (4 scans) to the weld axis. Before performing the angle beam examinations, a straight beam examination shall be performed on the volume of base material through which the angle beams will travel to locate any reflectors that can limit the ability of the angle beam to examine the weld volume.

T-472.1 Angle Beam Technique

T-472.1.1 Beam Angle. The search unit and beam 04 angle selected shall be 45 deg or an angle appropriate for the configuration being examined and shall be capable of detecting the calibration reflectors, over the required angle beam path.

T-472.1.2 Reflectors Parallel to the Weld Seam. The angle beam shall be directed at approximate right angles to the weld axis from both sides of the weld (i.e., from two directions) on the same surface when possible. The search unit shall be manipulated so that the ultrasonic energy passes through the required volume of weld and adjacent base material.

T-472.1.3 Reflectors Transverse to the Weld 04 **Seam.** The angle beam shall be directed essentially parallel to the weld axis. The search unit shall be manipulated

[3] When the Referencing Code Section requires the detection and evaluation of all indications exceeding 20% DAC, the gain should be increased an additional amount so that no calibration reflector indication is less than 40% FSH. As an alternate, the scanning sensitivity level may be set at 14 dB higher than the reference level gain setting. (This additional gain makes the reference DAC curve a 20% DAC curve so that indications exceeding 20% DAC may be easily identified and evaluated.).

so that the ultrasonic energy passes through the required volume of weld and adjacent base material. The search unit shall be rotated 180 deg and the examination repeated.

If the weld cap is not machined or ground flat, the examination shall be performed from the base metal on both sides of the weld cap in both weld axis directions.

T-472.2 Restricted Access Welds. Welds that cannot be fully examined from two directions using the angle beam technique (e.g., corner and tee joints) shall also be examined, if possible, with a straight beam technique. These areas of restricted access shall be noted in the examination report.

T-472.3 Inacessible Welds. Welds that cannot be examined from at least one side (edge) using the angle beam technique shall be noted in the examination report. For flange welds, the weld may be examined with a straight beam or low angle longitudinal waves from the flange face provided the examination volume can be covered.

T-473 Cladding Techniques

The techniques described in these paragraphs shall be used when examinations of weld metal overlay cladding are required by a referencing Code Section. When examination for lack of bond and clad flaw indications is required, Technique One shall be used. When examination for lack of bond only is required, Technique Two may be used.

T-473.1 Technique One. The examination shall be performed from the clad surface with the plane separating the elements of the dual element search unit positioned parallel to the axis of the weld bead. The search unit shall be moved perpendicular to the weld direction.

T-473.2 Technique Two. The examination may be performed from either the clad or unclad surface and the search unit may be moved either perpendicular or parallel to the weld direction.

T-474 Non-Distance Amplitude Techniques

The number of angles and directions of the scans shall be developed in the procedure and shall demonstrate the ability to detect the minimum size rejectable discontinuities in the referencing Code Section acceptance standards. The detailed techniques shall be in conformance with the requirements of the referencing Code Section.

T-480 EVALUATION

T-481 General

It is recognized that not all ultrasonic reflectors indicate flaws, since certain metallurgical discontinuities and geometric conditions may produce indications that are not relevant. Included in this category are plate segregates in the heat-affected zone that become reflective after fabrication. Under straight beam examination, these may appear as spot or line indications. Under angle beam examination, indications that are determined to originate from surface conditions (such as weld root geometry) or variations in metallurgical structure in austenitic materials (such as the automatic-to-manual weld clad interface) may be classified as geometric indications. The identity, maximum amplitude, location, and extent of reflector causing a geometric indication shall be recorded. [For example: internal attachment, 200% DAC, 1 in. (25 mm) above weld center line, on the inside surface, from 90 deg to 95 deg.] The following steps shall be taken to classify an indication as geometric:

(a) Interpret the area containing the reflector in accordance with the applicable examination procedure.

(b) Plot and verify the reflector coordinates. Prepare a cross-sectional sketch showing the reflector position and surface discontinuities such as root and counterbore.

(c) Review fabrication or weld preparation drawings. Other ultrasonic techniques or nondestructive examination methods may be helpful in determining a reflector's true position, size, and orientation.

T-482 Evaluation Level

T-482.1 Distance Amplitude Techniques. All indications greater than 20% of the reference level shall be investigated to the extent that they can be evaluated in terms of the acceptance criteria of the referencing Code Section.

T-482.2 Non-Distance Amplitude Techniques. All indications longer than 40% of the rejectable flaw size shall be investigated to the extent that they can be evaluated in terms of the acceptance criteria of the referencing Code Section.

T-483 Evaluation of Laminar Reflectors

Reflectors evaluated as laminar reflectors in base material which interfere with the scanning of examination volumes shall require the angle beam examination technique to be modified such that the maximum feasible volume is examined, and shall be noted in the record of the examination (T-493).

T-484 Alternative Evaluations

Reflector dimensions exceeding the referencing Code Section requirements may be evaluated to any alternative standards provided by the referencing Code Section.

T-490 DOCUMENTATION

T-491 Recording Indications

T-491.1 Non-Rejectable Indications. Non-rejectable indications shall be recorded as specified by the referencing Code Section.

T-491.2 Rejectable Indications. Rejectable indications shall be recorded. As a minimum, the type of indication (i.e., crack, non-fusion, slag, etc.), location, and extent (i.e., length) shall be recorded.

T-492 Examination Records

For each ultrasonic examination, the following information shall be recorded:

(a) procedure identification and revision;

(b) ultrasonic instrument identification (including manufacturer's serial number);

(c) search unit(s) identification (including manufacturer's serial number, frequency, and size);

(d) beam angle(s) used;

(e) couplant used, brand name or type;

(f) search unit cable(s) used, type and length;

(g) special equipment when used (search units, wedges, shoes, automatic scanning equipment, recording equipment, etc.);

(h) computerized program identification and revision when used;

(i) calibration block identification;

(j) simulation block(s) and electronic simulator(s) identification when used;

(k) instrument reference level gain and, if used, damping and reject setting(s);

(l) calibration data [including reference reflector(s), indication amplitude(s), and distance reading(s)];

(m) data correlating simulation block(s) and electronic simulator(s), when used, with initial calibration;

(n) identification and location of weld or volume scanned;

(o) surface(s) from which examination was conducted, including surface condition;

(p) map or record of rejectable indications detected or areas cleared;

(q) areas of restricted access or inaccessible welds;

(r) examination personnel identity and, when required by referencing Code Section, qualification level;

(s) date of examination. A06

Items *(b)* through *(m)* may be included in a separate calibration record provided the calibration record identification is included in the examination record.

T-493 Report

A report of the examinations shall be made. The report shall include those records indicated in T-491 and T-492. The report shall be filed and maintained in accordance with the referencing Code Section.

ARTICLE 4
MANDATORY APPENDICES

APPENDIX I — SCREEN HEIGHT LINEARITY

I-410 SCOPE

This Mandatory Appendix provides requirements for checking screen height linearity and is applicable to ultrasonic instruments with A-scan displays.

I-440 MISCELLANEOUS REQUIREMENTS

Position an angle beam search unit on a calibration block, as shown in Fig. I-440 so that indications from both the $\frac{1}{2}$ and $\frac{3}{4}T$ holes give a 2:1 ratio of amplitudes between the two indications. Adjust the sensitivity (gain) so that the larger indication is set at 80% of full screen height (FSH). Without moving the search unit, adjust sensitivity (gain) to successively set the larger indication from 100% to 20% of full screen height, in 10% increments (or 2 dB steps if a fine control is not available), and read the smaller indication at each setting. The reading shall be 50% of the larger amplitude, within 5% of FSH. The settings and readings shall be estimated to the nearest 1% of full screen. Alternatively, a straight beam search unit may be used on any calibration block that provides amplitude differences, with sufficient signal separation to prevent overlapping of the two signals.

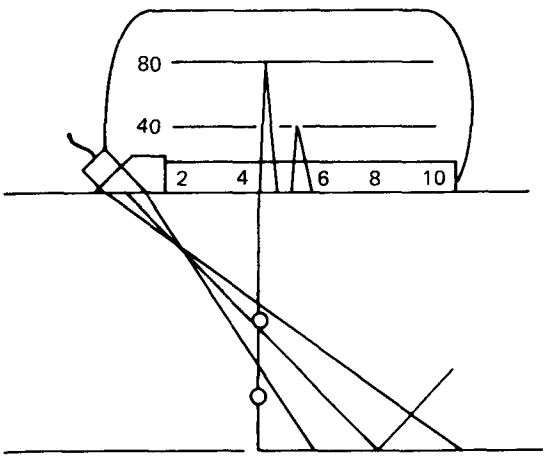


FIG. I-440 LINEARITY

APPENDIX II — AMPLITUDE CONTROL LINEARITY

II-410 SCOPE

This Mandatory Appendix provides requirements for checking amplitude control linearity and is applicable to ultrasonic instruments with A-scan displays.

II-440 MISCELLANEOUS REQUIREMENTS

Position an angle beam search unit on a basic calibration block, as shown in Fig. I-440 so that the indication from the $\frac{1}{2}T$ side-drilled hole is peaked on the screen. Adjust the sensitivity (gain) as shown in the following table. The indication shall fall within the specified limits. Alternatively, any other convenient reflector from any calibration block may be used with angle or straight beam search units.

Indication Set at % of Full Screen	dB Control Change	Indication Limits % of Full Screen
80%	–6 dB	32 to 48%
80%	–12 dB	16 to 24%
40%	+6 dB	64 to 96%
20%	+12 dB	64 to 96%

The settings and readings shall be estimated to the nearest 1% of full screen.

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APPENDIX III — TIME OF FLIGHT DIFFRACTION (TOFD) TECHNIQUE

III-410 SCOPE

This Mandatory Appendix describes the requirements to be used for a Time of Flight Diffraction (TOFD) examination of welds.

III-420 GENERAL

The requirements of Article 4 apply unless modified by this Appendix.

III-422 Written Procedure Requirements

III-422.1 Requirements. TOFD shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements listed in Tables T-422 and III-422. The written procedure shall establish a single value, or range of values, for each requirement.

III-422.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Tables T-422 or III-422 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

III-430 EQUIPMENT

III-431 Instrument Requirements

III-431.1 Instrument. The instrument shall provide a linear "A" scan presentation for both setting up scan parameters and for signal analysis. Instrument linearity shall be such that the accuracy of indicated amplitude or time is ±5% of the actual full-scale amplitude or time. The ultrasonic pulser may provide excitation voltage by tone burst, unipolar, or bipolar square wave. Pulse width shall be tunable to allow optimization of pulse amplitude and duration. The bandwidth of the ultrasonic receiver shall be at least equal to that of the nominal probe frequency and such that the −6dB bandwidth of the probe does not fall outside of the −6dB bandwidth of the receiver. Receiver gain control shall be available to adjust signal amplitude in increments of 1dB or less. Pre-amplifiers may be included in the system. Analog to digital conversion of waveforms shall have sampling rates at least four times that of the nominal frequency of the probe. When digital signal processing is to be carried out on the raw data, this shall be increased to eight times the nominal frequency of the probe.

TABLE III-422
REQUIREMENTS OF A TOFD EXAMINATION PROCEDURE

Requirement (As Applicable)	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	...
Instrument software	X	...
Directions and extent of scanning	X	...
Method for sizing flaw length	X	...
Method for sizing flaw height	X	...
Data sampling spacing (increase only)	X	...

III-431.2 Data Display and Recording. The data display shall allow for the viewing of the unrectified A-scan so as to position the start and length of a gate that determines the extent of the A-scan time-base that is recorded. Equipment shall permit storage of all gated A-scans to a magnetic or optical storage medium. Equipment shall provide a sectional view of the weld with a minimum of 64 gray scale or color levels. (Storage of just sectional images without the underlying A-scan RF waveforms is not acceptable.) Computer software for TOFD displays shall include algorithms to linearize cursors or the waveform time-base to permit depth and vertical extent estimations. In addition to storage of waveform data including amplitude and time-base details, the equipment shall also store positional information indicating the relative position of the waveform with respect to the adjacent waveform(s), i.e., encoded position.

III-432 Search Units

III-432.1 General. Ultrasonic probes shall conform to the following minimum requirements:

(a) Two probes shall be used in a pitch-catch arrangement (TOFD pair).

(b) Each probe in the TOFD pair shall have the same nominal frequency.

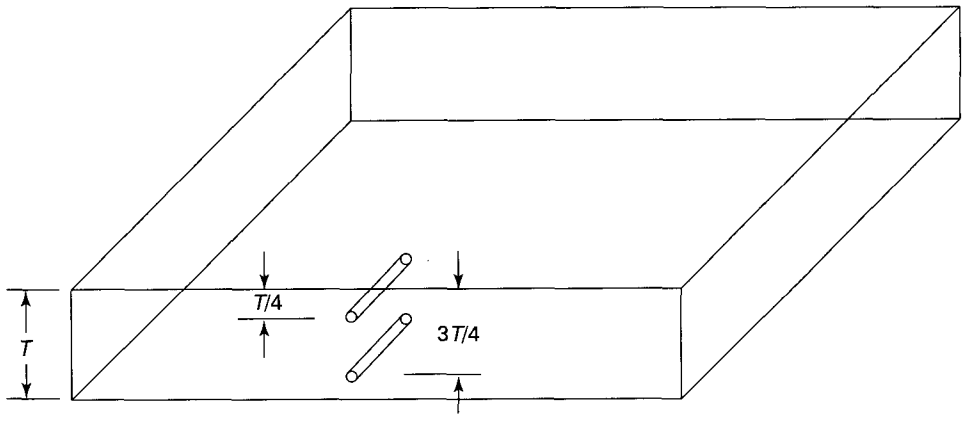
(c) The TOFD pair shall have the same element dimensions.

(d) The pulse duration of the probe shall not exceed 2 cycles as measured to the 20dB level below the peak response.

(e) Probes may be focused or unfocused. Unfocused probes are recommended for detection and focused probes are recommended for improved resolution for sizing.

(f) Probes may be single element or phased array.

(g) The nominal frequency shall be from 2 MHz to 15MHz unless variables, such as production material



Weld Thickness, in. (mm)	Hole Diameter, in. (mm)
Up to 1 (25)	3/32 (2.4)
Over 1 (25) thru 2 (50)	1/8 (3.2)
Over 2 (50) thru 4 (100)	3/16 (4.8)
Over 4 (100)	1/4 (6)

GENERAL NOTES:

(a) Holes shall be drilled and reamed 2 in. (50 mm) deep minimum, essentially parallel to the examination surface.

(b) *Hole Tolerance.* The tolerance on diameter shall be ± 1/32 in. (± 0.8 mm). The tolerance on location through the block thickness shall be ± 1/8 in. (± 3.2 mm).

(c) All holes shall be located on the same face (side) of the block and aligned at the approximate center of the face (side).

(d) When the weld is broken up into multiple zones, each zone shall have a $T_z/4$ and $T_z3/4$ side drilled hole, where T_z is the zone thickness.

FIG. III-434.2.1(a) TOFD REFERENCE BLOCK

grain structure, require the use of other frequencies to assure adequate penetration or better resolution.

III-432.2 Cladding — Search Units for Technique One. The requirements of T-432.2 are not applicable to the TOFD technique.

III-434 Calibration Blocks

III-434.1.1 Reflectors. Side drilled holes shall be used to confirm adequate sensitivity settings.

III-434.2.1 Basic Calibration Block. The basic calibration block configuration and reflectors shall be as shown in Fig. III-434.2.1(a). A minimum of two holes per zone, if the weld is broken up into multiple zones, is required. See Fig. III-434.2.1(b) for a two zone example. The block size and reflector location shall be adequate to confirm adequate sensitivity settings for the beam angles used.

III-434.2.2 Block Thickness. The block thickness shall be at ±10% of the nominal thickness of the piece to be examined for thicknesses up to 4 in. (100 mm) or ±0.4 in. (10 mm) for thicknesses over 4 in. (100 mm). Alternatively, a thicker block may be utilized provided the reference reflector size is based on the thickness to be examined and an adequate number of holes exist to comply with III-434.2.1 requirements.

III-434.2.3 Block Range of Use. The requirements of T-434.2.3 are not applicable to the TOFD technique.

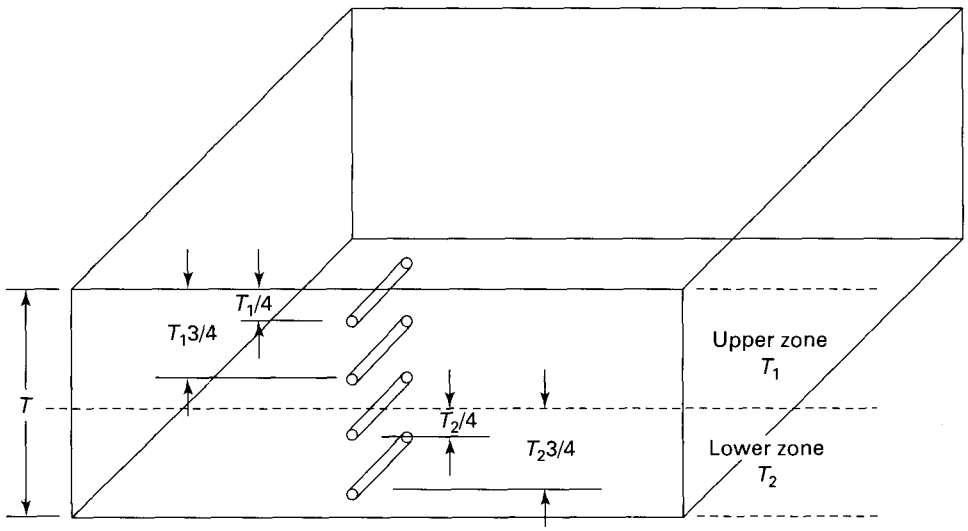
III-434.2.4 Alternate Block. The requirements of T-434.2.4 are not applicable to the TOFD technique.

III-434.3 Piping Calibration Block. The requirements of T-434.3 are not applicable to the TOFD technique.

III-434.4 Cladding Calibration Blocks. The requirements of T-434.4 are not applicable to the TOFD technique.

III-434 Mechanics

Mechanical holders shall be used to ensure that probe spacing is maintained at a fixed distance. The mechanical holders shall also ensure that alignment to the intended scan axis on the examination piece is maintained. Probe motion may be achieved using motorized or manual means and the mechanical holder for the probes shall be equipped with a positional encoder that is synchronized with the sampling of A-scans.



GENERAL NOTES:
(a) T_1 equals the thickness of the upper zone.
(b) T_2 equals the thickness of the lower zone.

FIG III-434.2.1(b) TWO-ZONE REFERENCE BLOCK EXAMPLE

III-460 CALIBRATION

III-463 Calibration for Nonpiping

III-463.1 Calibration Block. Calibration shall be performed utilizing the calibration block shown in Fig. 434.2.1(a) or on the material to be examined.

III-463.2 Calibration. Set the TOFD probes on the surface to be utilized for calibration and set the gain control so that the lateral wave amplitude is from 40% to 90% of the full screen height (FSH) and the noise (grass) level is less than 5–10% FSH. This is the reference sensitivity setting. For multiple zone examinations when the lateral wave is not displayed, or barely discernible, set the gain control based solely on the noise (grass) level.

III-463.3 Confirmation of Sensitivity. Scan the calibration block's SDHs with them centered between the probes, at the reference sensitivity level set in III-463.2. The SDH with the weakest response shall display an indication of 80% of FSH minimum.

III-463.4 Multiple Zone Examinations. When a weld is broken up into multiple zones, repeat III-463.2 and III-463.3 for each TOFD probe pair. In addition, the nearest SDH in the adjoining zone(s) shall be detected.

III-463.5 Width of Coverage Confirmation. Two additional scans per III-463.3 shall be made with the probes offset to either side of the applicable zone's weld edge ±½ in. (13 mm). If all the required holes are not detected, two additional offset scans are required with the probes offset by the distance(s) identified above. See Fig. III-463.5 for an example.

III-463.6 Encoder. Encoders shall be calibrated per the manufacturer's recommendations and confirmed by moving a minimum distance of 20 in. (500 mm) and the displayed distance being ±1% of the actual distance moved.

III-464 Calibration for Piping

The requirements of T-464 are not applicable to the TOFD technique.

III-465 Calibration for Cladding

The requirements of T-465 are not applicable to the TOFD technique.

III-467 Encoder Confirmation

A calibration check shall be performed at intervals not to exceed one month or prior to first use thereafter, made by moving the encoder along a minimum distance of 20 in. (500 mm) and the displayed distance being ±1% of the acutal distance moved.

III-470 EXAMINATION

III-471.1 Examination Coverage. The volume to be scanned shall be examined with the TOFD probe pair

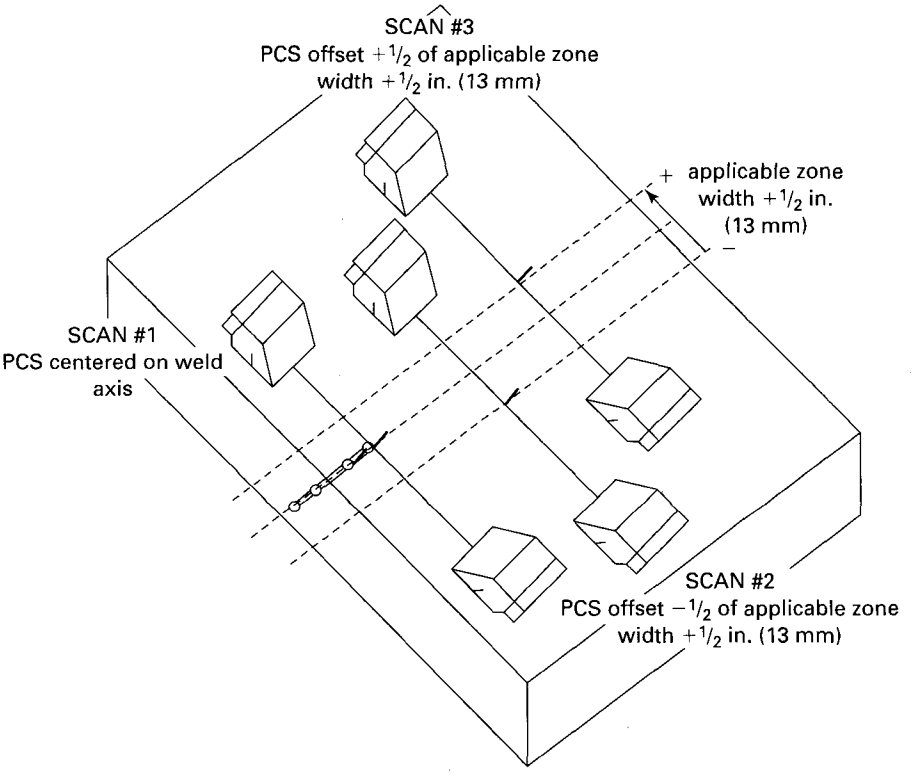


FIG. III-463.5 OFFSET SCANS

centered on and transverse to the weld axis and then moving the probe pair parallel to and along the weld axis. If offset scans are required due to the width of the weld, repeat the initial scan with the probes offset to one side of the weld axis and again with the offset to the opposite side of the first offset scan.

III-471.4 Overlap. The minimum overlap between adjacent scans shall be 1 in. (25 mm).

III-471.5 Multiple Zone Examination. When a weld is broken down into multiple zones, repeat III-471.1 for each weld zone.

III-471.6 Recording Data (Gated Region). The unrectified (RF waveform) A-scan signal shall be recorded. The A-scan gated region shall be set to start just prior to the lateral wave and, as a minimum, not end until all of the first back-wall signal with allowance for thickness and mismatch variations, is recorded. Useful data can be obtained from mode-converted signals; therefore, the interval from the first back-wall to the mode-converted back-wall signal shall also be included in the data collected when required by the referencing Code.

III-471.8 Transverse Examination. When required by the referencing Code Section, position each TOFD probe pair essentially parallel to the weld axis and move the probe pair along and down the weld axis. If the weld reinforcement is not ground smooth, position the probes on the adjacent plate material as parallel to the weld axis as possible.

III-471.9 Supplemental Shear Wave Examination. Due to the presence of the lateral wave and back-wall indication signals, flaws occurring in these zones may not be detected. Therefore, the weld's near surfaces (i.e., both top and bottom faces) shall be angle beam examined per Article 4 requirements with the angles chosen that are closest to being perpendicular to the fusion lines. This examination may be performed manually or mechanized; if mechanized, the data shall be collected in conjunction with the TOFD examination.

III-472 Weld Joint Distance Amplitude Technique

The requirements of T-472 are not applicable to the TOFD technique.

III-473 Cladding Technique

The requirements of T-473 are not applicable to the TOFD technique.

III-475 Data Sampling Spacing

A maximum sample spacing of 0.040 in. (1 mm) shall be used between A-scans collected for thicknesses under 2 in. (50 mm) and a sample spacing of up to 0.080 in. (2 mm) may be used for thicknesses greater than 2 in. (50 mm).

III-485 Missing Data Lines

Missing lines in the display shall not exceed 5% of the scan lines to be collected, and no adjacent lines shall be missed.

III-486 Flaw Sizing and Interpretation

When height of flaw sizing is required, after the system is calibrated per III-643, a free run on the calibration block shall be performed and the depth of the back-wall reflection calculated by the system shall be ±0.4 in. (1 mm) of the actual thickness. For multiple zone examinations where the back wall is not displayed or barely discernible, a side drilled hole in the calibration block shall be used. See Nonmandatory Appendix N of this Article for additional information on flaw sizing and interpretation.

III-490 DOCUMENTATION

III-492 Examination Record

For each examination, the required information in T-492 and the following information shall be recorded:

(a) probe center spacing (PCS)
(b) data sampling spacing
(c) flaw height, if specified

III-493 Report

A report of the examination shall be made. The report shall include those records indicated in T-491, T-492, and III-492. The report shall be filed and maintained in accordance with the referencing Code Section.

A06

APPENDIX IV — PHASED ARRAY, SINGLE FIXED ANGLE WITH MANUAL RASTER SCANNING

IV-410 SCOPE

This Mandatory Appendix describes the requirements to be used for a manual phased array ultrasonic examination utilizing a single fixed angle with manual raster scanning.

TABLE IV-422
REQUIREMENTS OF A PHASED ARRAY, SINGLE FIXED ANGLE WITH MANUAL RASTER SCANNING EXAMINATION PROCEDURE

Requirements (As Applicable)	Essential Variable	Nonessential Variable
Search unit type, element size and number, and pitch and gap dimensions	X	...
Focus range (identifying plane, depth, or sound path, as applicable)	X	...

IV-420 GENERAL

The requirements of Article 4 apply except as modified by this Appendix.

IV-422 Written Procedure Requirements

IV-422.1 Requirements. Phased array, single fixed angle with manual raster scanning shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements listed in Tables T-422 and III-422. The written procedure shall establish a single value or range of values for each requirement.

IV-422.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

IV-461 Instrument Linearity Checks

IV-461.2 Amplitude Control Linearity. The ultrasonic instrument's amplitude control linearity shall be evaluated in accordance with Mandatory Appendix III for each pulser-receiver circuit.

IV-462 General Calibration Requirements

IV-462.7 Focal Law.[1] The focal law to be used during the examination shall be used for calibration.

IV-492 Examination Record

For each examination, the required information of T-492 and the following information shall be recorded:

[1] *Focal law* is defined as a phased array operational file that defines the search unit elements and their time delays, for both the transmitter and receiver function.

(a) search unit type, element size and number, and pitch and gap dimensions

(b) focal law parameters, including angle, focal depth, and elements used

ARTICLE 4
NONMANDATORY APPENDICES

APPENDIX A — LAYOUT OF VESSEL REFERENCE POINTS

A-410 SCOPE

This Appendix provides requirements for establishing vessel reference points.

A-440 MISCELLANEOUS REQUIREMENTS

The layout of the weld shall consist of placing reference points on the center line of the weld. The spacing of the reference points shall be in equal increments (e.g., 12 in., 3 ft, 1 m, etc.) and identified with numbers (e.g., 0, 1, 2, 3, 4, etc.). The increment spacing, number of points, and starting point shall be recorded on the reporting form. The weld center line shall be the divider for the two examination surfaces.

A-441 Circumferential (Girth) Welds

The standard starting point shall be the 0 deg axis of the vessel. The reference points shall be numbered in a clockwise direction, as viewed from the top of the vessel or, for horizontal vessels, from the inlet end of the vessel. The examination surfaces shall be identified (e.g., for vertical vessels, as being either above or below the weld).

A-442 Longitudinal Welds

Longitudinal welds shall be laid out from the center line of circumferential welds at the top end of the weld or, for horizontal vessels, the end of the weld closest to the inlet end of the vessel. The examination surface shall be identified as clockwise or counterclockwise as viewed from the top of the vessel or, for horizontal vessels, from the inlet end of the vessel.

A-443 Nozzle-to-Vessel Welds

The external reference circle shall have a sufficient radius so that the circle falls on the vessel's external surface beyond the weld's fillet. The internal reference circle shall have a sufficient radius so that the circle falls within $\frac{1}{2}$ in. (13 mm) of the weld center-line. The 0 deg point on the weld shall be the top of the nozzle. The 0 deg point for welds of veritcally oriented nozzles shall be located at the 0 deg axis of the vessel, or, for horizontal vessels, the point closest to the inlet end of the vessel. Angular layout of the weld shall be made clockwise on the external surface and counterclockwise on the internal surface. The 0 deg, 90 deg, 180 deg, and 270 deg lines will be marked on all nozzle welds examined; 30 deg increment lines shall be marked on nozzle welds greater than a nominal 8 in. (200 mm) diameter; 15 deg increment lines shall be marked on nozzle welds greater than a nominal 24 in. (600 mm) diameter; 5 deg increment lines shall be marked on nozzle welds greater than 48 in. (1 200 mm) diameter.

APPENDIX B — GENERAL TECHNIQUES FOR ANGLE BEAM CALIBRATIONS

B-410 SCOPE 04

This Appendix provides general techniques for angle beam calibration. Other techniques may be used.

Descriptions and figures for the general techniques relate position and depth of the reflector to eighths of the V-path. The sweep range may be calibrated in terms of units of metal path,[1] projected surface distance or actual depth to the reflector (as shown in Figs. B-461.1, B-461.2, and B-461.3). The particular method may be selected according to the preference of the examiner.

B-460 CALIBRATION 04

B-461 Sweep Range Calibration

B-461.1 Side Drilled Holes (See Fig. B-461.1.1)

B-461.1.1 Delay Control Adjustment. Position the search unit for the maximum first indication from the

[1] Reflections from concentric cylindrical surfaces such as provided by some IIW blocks and the AWS distance calibration block may be used to adjust delay zero and sweep range for metal path calibration.

$\frac{1}{4}T$ side-drilled hole (SDH). Adjust the left edge of this indication to line 2 on the screen with the delay control.

B-461.1.2 Range[2] Control Adjustment. Position the search unit for the maximum indication from the $\frac{3}{4}T$ SDH. Adjust the left edge of this indication to line 6 on the screen with the range control.

B-461.1.3 Repeat Adjustments. Repeat delay and range control adjustments until the $\frac{1}{4}T$ and $\frac{3}{4}T$ SDH indications start at sweep lines 2 and 6.

B-461.1.4 Notch Indication. Position the search unit for maximum response from the square notch on the opposite surface. The indication will appear near sweep line 8.

B-461.1.5 Sweep Readings. Two divisions on the sweep now equal $\frac{1}{4}T$.

B-461.2 IIW Block (See Fig. B-461.2). IIW Reference Blocks may be used to calibrate the sweep range displayed on the instrument screen. They have the advantage of providing reflectors at precise distances that are not affected by side drilled hole location inaccuracies in the basic calibration block or the fact that the reflector is not at the side drilled hole centerline. These blocks are made in a variety of alloys and configurations. Angle beam range calibrations are provided from the 4 in. (100 mm) radius and other reflectors. The calibration block shown in Fig. B-461.2 provides an indication at 4 in. (100 mm) and a second indication from a reflection from the vertical notches at the center point 8 in. (200 mm) back to the radius and returning to the transducer when the exit point of the wedge is directly over the center point of the radius. Other IIW blocks provide signals at 2 in. (50 mm) and 4 in. (100 mm) and a third design provides indications at 4 in. (100 mm) and 9 in. (225 mm).

B-461.2.1 Search Unit Adjustment. Position the search unit for the maximum indication from the 4 in. (100 mm) radius while rotating it side to side to also maximize the second reflector indication.

B-461.2.2 Delay and Range Control Adjustment. Without moving the search unit, adjust the range and delay controls so that the indications start at their respective metal path distances.

B-461.2.3 Repeat Adjustments. Repeat delay and range control adjustments until the two indications are at their proper metal path on the screen.

B-461.2.4 Sweep Readings. Two divisions on the sweep now equal $\frac{1}{5}$ of the screen range selected.

[2] Range has been replaced on many new instruments with "velocity".

B-461.3 Piping Block (See Fig. B-461.3). The notches in piping calibration blocks may be used to calibrate the distance range displayed on the instrument screen. They have the advantage of providing reflectors at precise distances to the inside and outside surfaces.

B-461.3.1 Delay Control Adjustment. Position the search unit for the maximum first indication from the inside surface notch at its actual beam path on the instrument screen. Adjust the left edge of this indication to its metal path on the screen with the delay control.

B-461.3.2 Range Control Adjustment. Position the search unit for the maximum second indication from the outside surface notch. Adjust the left edge of this indication to its metal on the screen with the range control or velocity control.

B-461.3.3 Repeat Adjustments. Repeat delay and range control adjustments until the two indications are at their proper metal paths on the screen.

B-461.3.4 Sweep Readings. Two divisions on the sweep now equal $\frac{1}{5}$ of the screen range selected.

B-462 Distance–Amplitude Correction

B-462.1 Calibration for Side Drilled Holes Primary Reference Level From Clad Side (See Fig. B-462.1)

(a) Position the search unit for maximum response from the SDH, which gives the highest amplitude.

(b) Adjust the sensitivity (gain) control to provide an indication of 80% (±5%) of full screen height (FSH). Mark the peak of the indication on the screen.

(c) Position the search unit for maximum response from another SDH.

(d) Mark the peak of the indication on the screen.

(e) Position the search unit for maximum amplitude from the third SDH and mark the peak on the screen.

(f) Position the search unit for maximum amplitude from the $\frac{3}{4}T$ SDH after the beam has bounced from the opposite surface. The indication should appear near sweep line 10. Mark the peak on the screen for the $\frac{3}{4}T$ position.

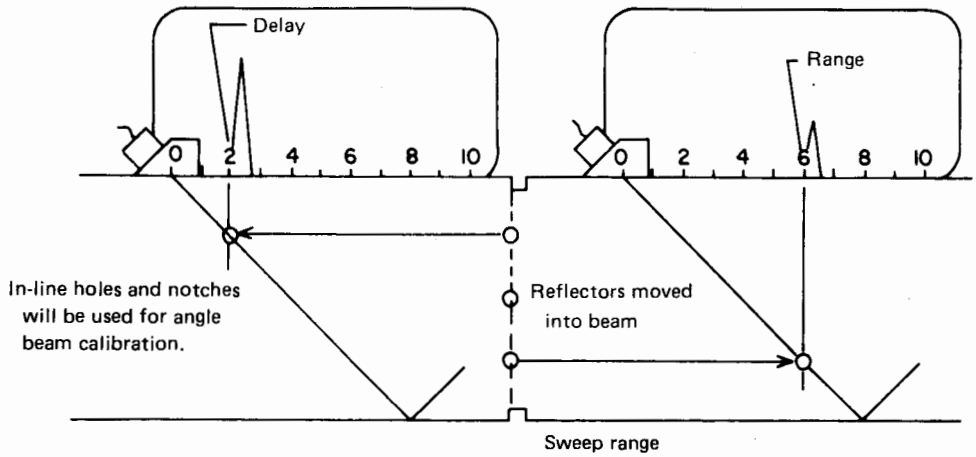
(g) Connect the screen marks for the SDHs to provide the distance–amplitude curve (DAC).

(h) For calibration correction for perpendicular reflectors at the opposite surface, refer to B-465.

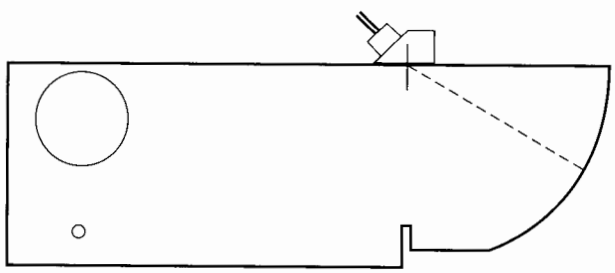
B-462.2 Calibration for Side Drilled Holes Primary Reference Level From Unclad Side (See Fig. B-462.1)

(a) From the clad side of the block, determine the dB change in amplitude between the $\frac{3}{4}T$ and $\frac{5}{4}T$ SDH positions.

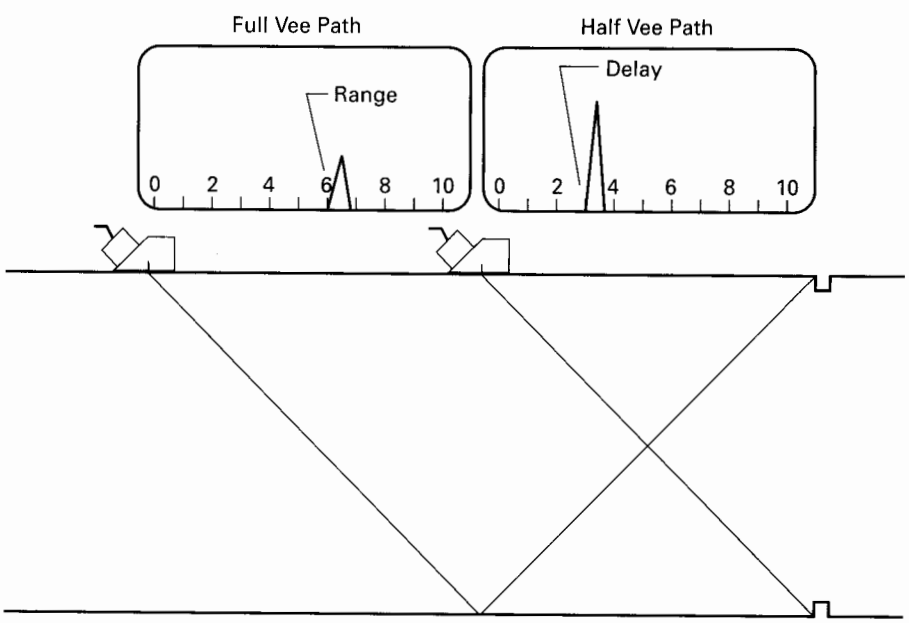
(b) From the unclad side, perform calibrations as noted in B-462.1(a) through B-462.1(e).



04 FIG. B-461.1 SWEEP RANGE (SIDE DRILLED HOLES)



04 A06 FIG. B-461.2 SWEEP RANGE (IIW BLOCK)



04 FIG. B-461.3 SWEEP RANGE (NOTCHES)

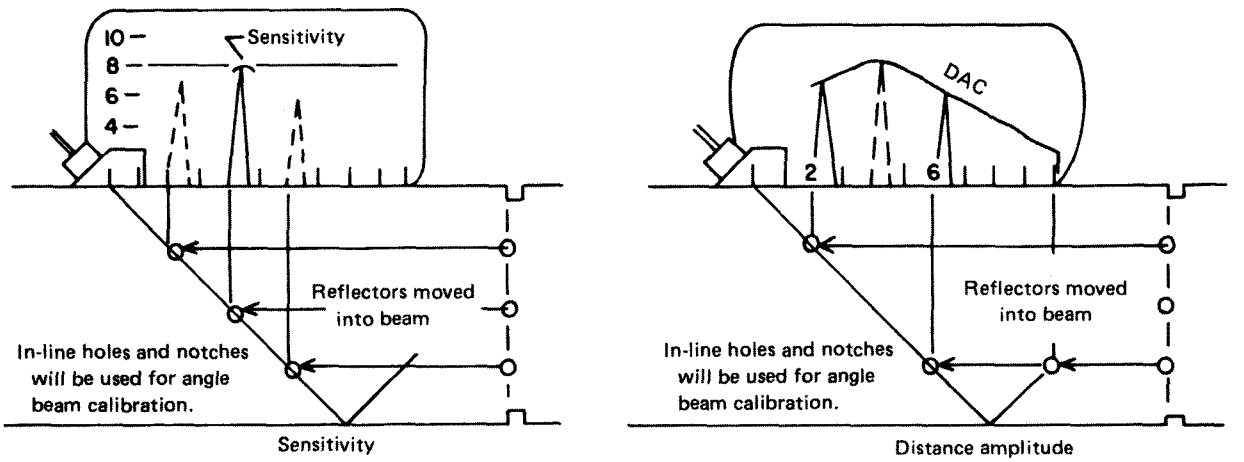


FIG. B-462.1 SENSITIVITY AND DISTANCE-AMPLITUDE CORRECTION (SIDE DRILLED HOLES) 04

(c) To determine the amplitude for the $^5/_4T$ SDH position, position the search unit for maximum amplitude from the $^3/_4T$ SDH. Decrease the signal amplitude by the number of dB determined in *(a)* above. Mark the height of this signal amplitude at sweep line 10 ($^5/_4T$ position).

(d) Connect the screen marks to provide the DAC. This will permit evaluation of indications down to the clad surface (near sweep line 8).

(e) For calibration correction for perpendicular planar reflectors near the opposite surface, refer to B-465.

B-462.3 Calibration for Piping Notches Primary Reference Level (See Fig. B-462.3)

(a) Position the search unit for maximum response from the notch which gives the highest amplitude.

(b) Adjust the sensitivity (gain) control to provide an indication of 80% (±5%) of full screen height (FSH). Mark the peak of the indication on the screen.

(c) Without changing the gain, position the search unit for maximum response from another notch.

(d) Mark the peak of the indication on the screen.

(e) Position the search unit for maximum amplitude from the remaining notch at its Half Vee, Full Vee or $^3/_2$ Vee beam paths and mark the peak on the screen.

(f) Position the search unit for maximum amplitude from any additional Vee Path(s) when used and mark the peak(s) on the screen.

(g) Connect the screen marks for the notches to provide the distance–amplitude curve (DAC).

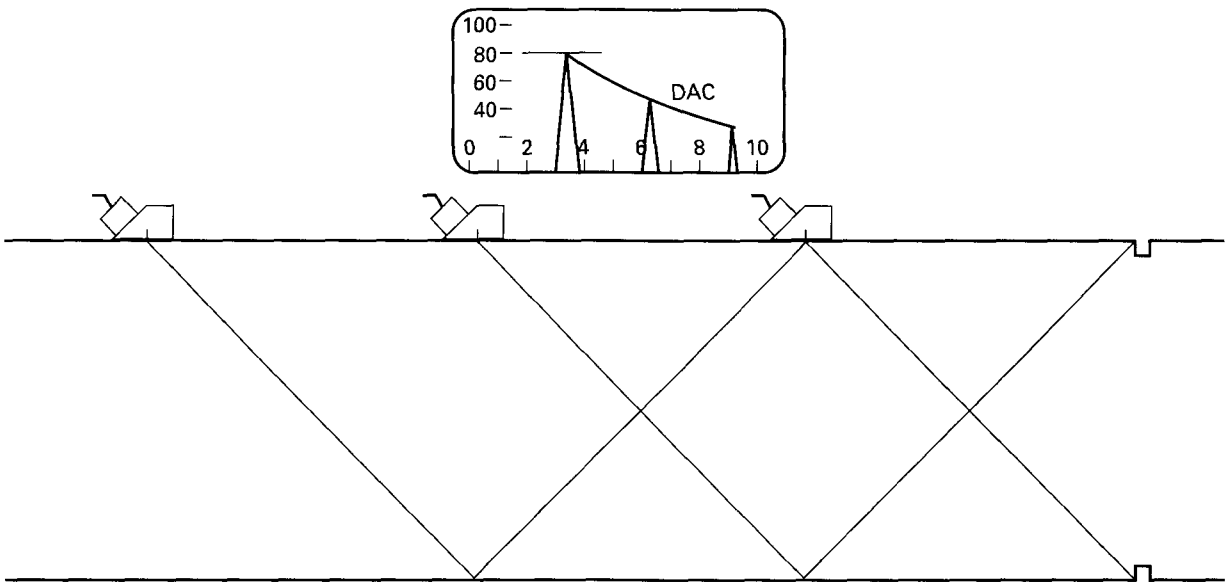
(h) These points also may be captured by the ultrasonic instrument and electronically displayed.

B-463 Distance–Amplitude Correction Inner ¼ Volume (See Appendix J, Fig. J-431 View A)

B-463.1 Number of Beam Angles. The ¼ volume angle calibration requirement may be satisfied by using one or more beams as required to calibrate on ⅛ in. (3 mm) maximum diameter side drilled holes in that volume.

B-463.2 Calibration From Unclad Surface. When the examination is performed from the outside surface, calibrate on the ⅛ in. (3 mm) diameter side drilled holes to provide the shape of the DAC from ½ in. (13 mm) to ¼ *T* depth. Set the gain to make the indication from ⅛ in. (3 mm) diameter side drilled hole at ¼ *T* depth the same height as the indication from the ¼ *T* depth hole as determined in B-462.1 or B-462.2 above. Without changing the gain, determine the screen height of the other near surface indications from the remaining ⅛ in. (3 mm) diameter side drilled holes from ½ in. (13 mm) deep to the ⅛ in. (3 mm) diameter side drilled hole just short of the ¼ *T* depth. Connect the indication peaks to complete the near surface DAC curve. Return the gain setting to that determined in B-462.1 or B-462.2.

B-463.3 Calibration From Clad Surface. When the examination is performed from the inside surface, calibrate on the ⅛ in. (3 mm) diameter side drilled holes to provide the shape of the DAC and the gain setting, as per B-463.2 above.



04 FIG. B-462.3 SENSITIVITY AND DISTANCE–AMPLITUDE CORRECTION (NOTCHES)

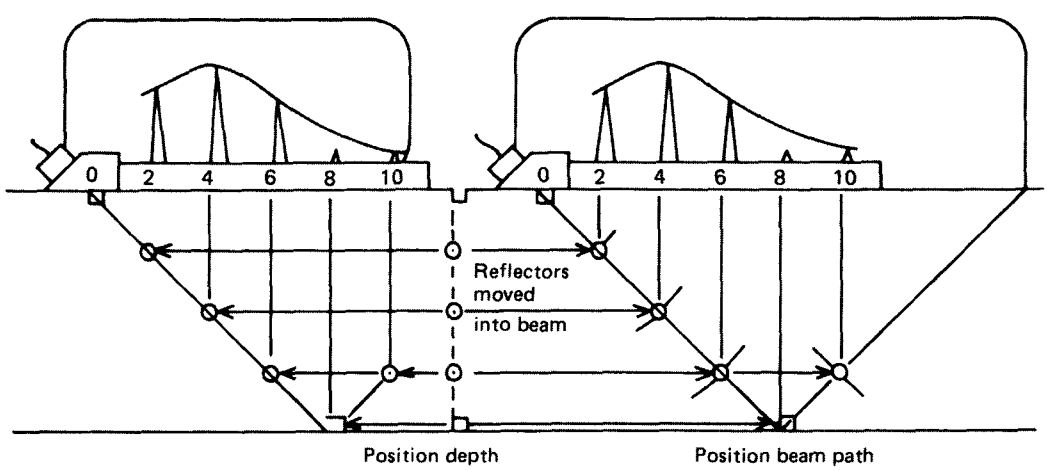


FIG. B-464 POSITION DEPTH AND BEAM PATH

B-464 Position Calibration (See Fig. B-464)

The following measurements may be made with a ruler, scale, or marked on an indexing strip.[3]

B-464.1 $\frac{1}{4}T$ SDH Indication. Position the search unit for maximum response from the $\frac{1}{4}T$ SDH. Place one end of the indexing strip against the front of the search unit, the other end extending in the direction of the beam. Mark the number 2 on the indexing strip at the scribe line which is directly above the SDH. (If the search unit covers the scribe line, the marks may be made on the side of the search unit.)

B-464.2 $\frac{1}{2}T$ and $\frac{3}{4}T$ SDH Indications. Position the search unit for maximum indications from the $\frac{1}{2}T$ and $\frac{3}{4}T$ SDHs. Keep the same end of the indexing strip against the front of the search unit. Mark the numbers 4 and 6 on the indexing strip at the scribe line, which are directly above the SDHs.

B-464.3 $\frac{5}{4}T$ SDH Indication. If possible, position the search unit so that the beam bounces from the opposite surface to the $\frac{3}{4}T$ SDH. Mark the number 10 on the

[3] The balance of the calibrations in this Appendix is written based upon the use of the indexing strip. However, the procedures may be transformed for other methods of measurements at the discretion of the examiner.

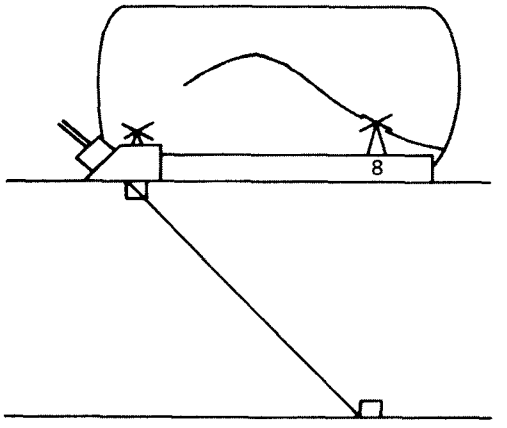


FIG. B-465 PLANAR REFLECTIONS

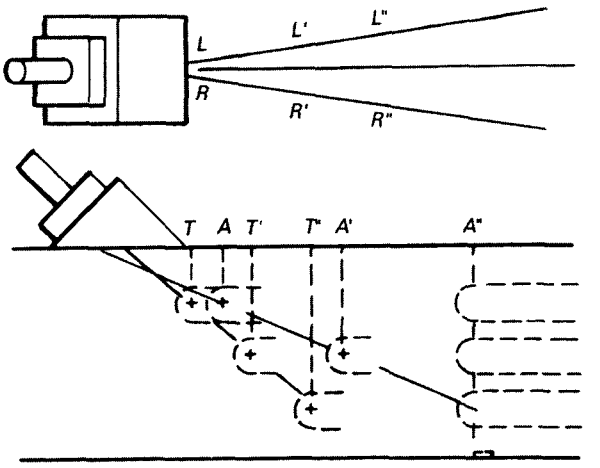


FIG. B-466 BEAM SPREAD

indexing strip at the scribe line, which is directly above the SDH.

B-464.4 Notch Indication. Position the search unit for the maximum opposite surface notch indication. Mark the number 8 on the indexing strip at the scribe line, which is directly above the notch.

B-464.5 Index Numbers. The numbers on the indexing strip indicate the position directly over the reflector in sixteenths of the V-path.

B-464.6 Depth. The depth from the examination surface to the reflector is T at 8, $\frac{3}{4}T$ at 6 and 10, $\frac{1}{2}T$ at 4, $\frac{1}{4}T$ at 2, and 0 at 0. Interpolation is possible for smaller increments of depth. The position marks on the indexing strip may be corrected for the radius of the hole if the radius is considered significant to the accuracy of reflector's location.

B-465 Calibration Correction for Planar Reflectors Perpendicular to the Examination Surface at or Near the Opposite Surface (See Fig. B-465)

A 45 deg angle beam shear wave reflects well from a corner reflector. However, mode conversion and redirection of reflection occurs to part of the beam when a 60 deg angle beam shear wave hits the same reflector. This problem also exists to a lesser degree throughout the 50 deg to 70 deg angle beam shear wave range. Therefore, a correction is required in order to be equally critical of such an imperfection regardless of the examination beam angle.

B-465.1 Notch Indication. Position the search unit for maximum amplitude from the notch on the opposite surface. Mark the peak of the indication with an "X" on the screen.

B-465.2 45 deg vs. 60 deg. The opposite surface notch may give an indication 2 to 1 above DAC for a 45 deg shear wave, but only $\frac{1}{2}$ DAC for a 60 deg shear wave. Therefore, the indications from the notch shall be considered when evaluating reflectors at the opposite surface.

B-466 Beam Spread (See Fig. B-466)

Measurements of beam spread shall be made on the hemispherical bottom of round bottom holes (RBHs). The half maximum amplitude limit of the primary lobe of the beam shall be plotted by manipulating the search unit for measurements on reflections from the RBHs as follows.

B-466.1 Toward $\frac{1}{4}T$ Hole. Set the maximum indication from the $\frac{1}{4}T$ RBH at 80% of FSH. Move search unit toward the hole until the indication equals 40% of FSH. Mark the beam center line "toward" position on the block.

B-466.2 Away From $\frac{1}{4}T$ Hole. Repeat B-466.1, except move search unit away from the hole until the indication equals 40% of FSH. Mark the beam center line "away" position on the block.

B-466.3 Right of $\frac{1}{4}T$ Hole. Reposition the search unit for the original 80% of FSH indication from the $\frac{1}{4}T$ RBH. Move the search unit to the right without pivoting the beam toward the reflector until the indication equals 40% of FSH. Mark the beam center line "right" position on the block.[4]

[4] When manually positioning the search unit, a straight edge may be used to guide the search unit while moving to the right and left to assure that axial positioning and beam alignment are maintained.

B-466.4 Left of $\frac{1}{4}T$ Hole. Repeat B-466.3, except move the search unit to the left without pivoting the beam toward the reflector until the indication equals 40% of FSH. Mark the beam center line "left" position on the block.[3]

B-466.5 $\frac{1}{2}T$ and $\frac{3}{4}T$ Holes. Repeat the steps in B-466.1 through B-466.4 for the $\frac{1}{2}T$ and $\frac{3}{4}T$ RBHs.

B-466.6 Record Dimensions. Record the dimensions from the "toward" to "away" positions and from the "right" to "left" positions marked on the block.

B-466.7 Perpendicular Indexing. The smallest of the three "toward" to "away" dimensions shall not be exceeded when indexing between scans perpendicular to the beam direction.

B-466.8 Parallel Indexing. The smallest of the three "right" to "left" dimensions shall not be exceeded when indexing between scans parallel to the beam direction.

B-466.9 Other Metal Paths. The projected beam spread angle determined by these measurements shall be used to determine limits as required at other metal paths.

NOTE If laminar reflectors are present in the basic calibration block, the beam spread readings may be affected; if this is the case, beam spread measurements must be based on the best available readings.

APPENDIX C — GENERAL TECHNIQUES FOR STRAIGHT BEAM CALIBRATIONS

C-410 SCOPE

This Appendix provides general techniques for straight beam calibration. Other techniques may be used.

C-460 CALIBRATION

04 **C-461 Sweep Range Calibration[5] (See Fig. C-461)**

C-461.1 Delay Control Adjustment. Position the search unit for the maximum first indication from the $\frac{1}{4}T$ SDH. Adjust the left edge of this indication to line 2 on the screen with the delay control.

C-461.2 Range Control Adjustment. Position the search unit for the maximum indication from $\frac{3}{4}T$ SDH. Adjust the left edge of this indication to line 6 on the screen with the range control.

[5] Calibration by beam path measurement may be used by range control positioning by the block back reflection to the sweep division number (or multiple) equal to the measured thickness. The $\frac{1}{4}T$ SDH indication must be delay control positioned to $\frac{1}{4}$ of the sweep division number.

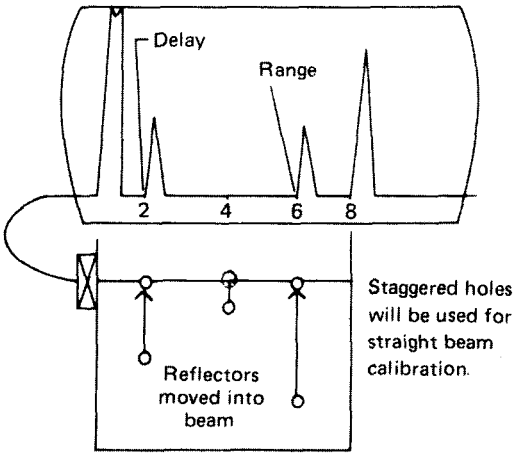


FIG. C-461 SWEEP RANGE

C-461.3 Repeat Adjustments. Repeat the delay and range control adjustments until the $\frac{1}{4}T$ and $\frac{3}{4}T$ SDH indications start at sweep lines 2 and 6.

C-461.4 Back Surface Indication. The back surface indication will appear near sweep line 8.

C-461.5 Sweep Readings. Two divisions on the sweep equal $\frac{1}{4}T$.

C-462 Distance–Amplitude Correction (See Fig. C-462)

The following is used for calibration from either the clad side or the unclad side:

(a) Position the search unit for the maximum indication from the SDH, which gives the highest indication.

(b) Adjust the sensitivity (gain) control to provide an 80% (±5%) of FSH indication. This is the primary reference level. Mark the peak of this indication on the screen.

(c) Position the search unit for maximum indication from another SDH.

(d) Mark the peak of the indication on the screen.

(e) Position the search unit for maximum indication from the third SDH and mark the peak on the screen.

(f) Connect the screen marks for the SDHs and extend through the thickness to provide the distance–amplitude curve.

APPENDIX D — DATA RECORD EXAMPLE FOR A PLANAR REFLECTOR

D-10 SCOPE

This Appendix provides an example of the data required to dimension a 120% DAC reflector found when

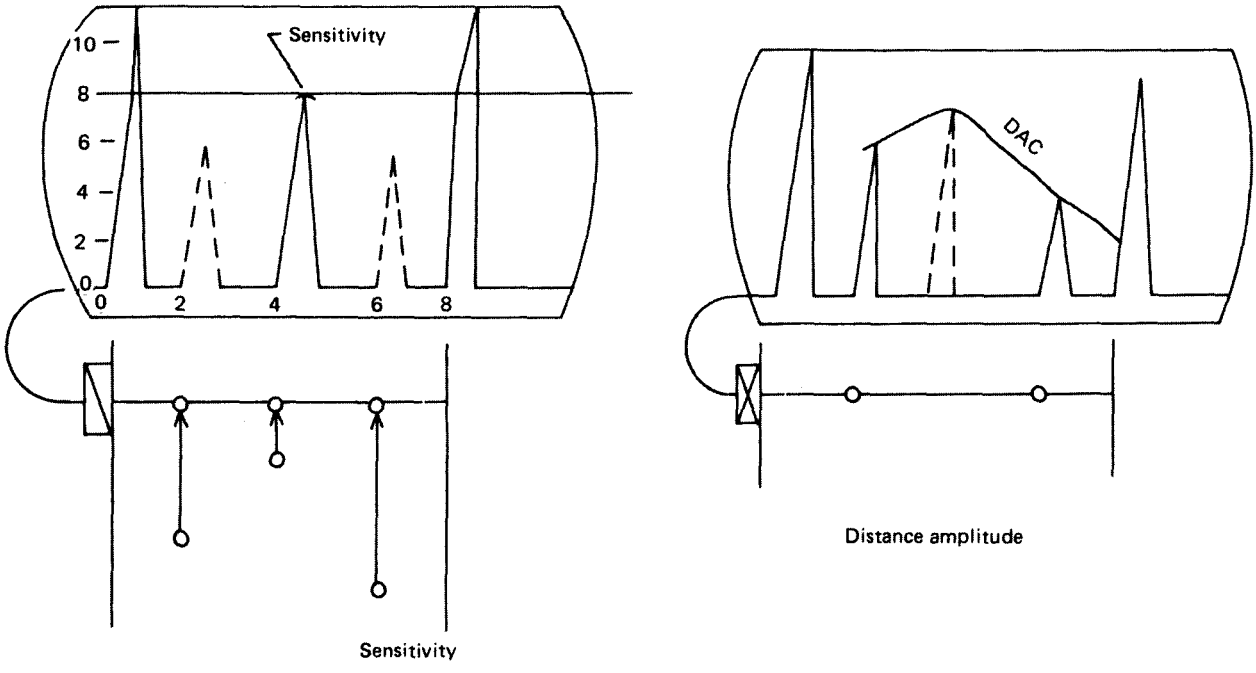


FIG. C-462 SENSITIVITY AND DISTANCE-AMPLITUDE CORRECTION

scanning perpendicular to a weld. Figure D-10 is an illustration of the maximum amplitude scan and tabulation of that data with additional scan data that might be taken on the reflector.

D-90 DOCUMENTATION

Position the search unit to give the maximum amplitude from the reflector.

(a) Read and record the *maximum* amplitude in *percent of DAC.*

(b) Read and record the *sweep reading* to reflector (at the left side of the indication on the sweep).

(c) Read and record the *search unit position* with respect to the reference line.

(d) Read and record the *location* of the indication at the beam center line intersection with respect to the reference line from the weld layout reference points.

Move the search unit toward the reflector until the amplitude falls to 60% DAC (half maximum amplitude).

(e) Read and record the *minimum sweep reading.*

(f) Read and record the *minimum search unit position.*

Move the search unit away from the reflector past the maximum amplitude position until the amplitude falls to 60% DAC (half maximum amplitude).

(g) Read and record the *maximum sweep reading.*

(h) Read and record the *maximum search unit position.*

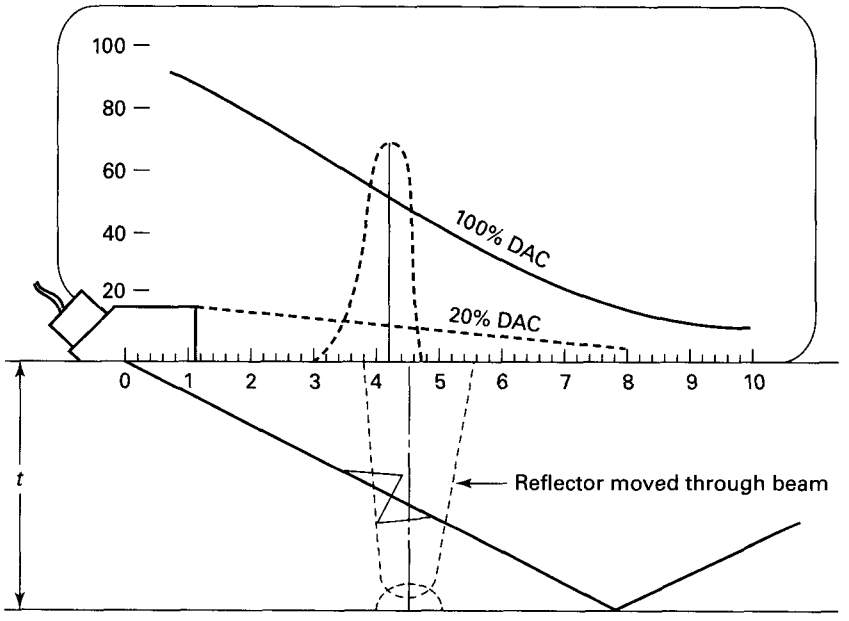
Data points *(a)* through *(h)* above shall be read and recorded during the examination. Computations for *(i)* depth, *(j)* distance from surface, and length of the reflector shall be made prior to completion of the examination report.

(i) Subtract the minimum sweep reading from the maximum sweep reading and divide by the sweep reading for one wall thickness. Multiply by 100 and record as *depth* in % of t (t = weld thickness)

(j) Subtract the maximum sweep reading from the sweep reading for one wall thickness or use the minimum sweep reading, whichever gives the smaller number. Divide the number by the sweep reading for one wall thickness. Multiply by 100 and record as *distance* from surface in % of t and length of reflection.

Successively read and record data along scan paths at increments no greater than nine-tenths of the transducer (measured parallel to the scan increment change) at 60% DAC (half maximum amplitude). Continue scans until the maximum amplitude found at the end points of the reflector is 20% DAC.

The length of the reflector is the distance between the end points measured at the reflector. The length shall be divided by t and multiplied by 100 to give length in % of t. The data tabulated in Fig. D-10 is carried out on either side of the maximum indicated signal until the 20% DAC point is reached on both ends of the indication. It



GENERAL NOTE: As the reflector is moved through the beam, the flaw indication reaches 20% DAC at 4.4 sweep divisions, increases in amplitude to 120% DAC at 4.0 sweep divisions, and falls to 20% DAC at 3.6 sweep divisions. The 20% DAC change in sweep reading, divided by the thickness sweep reading, times 100 represents the reflector depth (that is, 10% of t) or the 2 (a) dimension of the subsurface flaw indication.

FIG. D-10 REFLECTOR READING

DATA TABULATION FOR FIG. D-10

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	
				20% DAC				% of t		
				Minimum		Maximum				
Maximum % DAC	Sweep Reading	Search Unit Position, mm	Location, mm	Sweep Reading	Position	Sweep Reading	Position	Depth	Distance From Surface	Computation or Remarks
120	4.0	4.6	23	3.6	4.2	4.4	5.2	10	45	$\frac{4.4-3.6}{8.0}$
80	4.0	4.6	22.1	3.8	4.3	4.2	4.8	5	47.5	$\frac{4.2-3.8}{8.0}$
20	4.0	4.6	21.7	...	...	...	...	0	50	...
90	4.1	4.7	23.9	3.7	4.3	4.3	5.2	7.5	46	$\frac{4.3-3.7}{8.0}$
70	4.1	4.7	24.8	3.9	4.4	4.3	5.2	5	46	$\frac{4.3-3.9}{8.0}$
20	4.2	4.6	25	...	...	...	...	0	50	...
										depth: 10% of t
										length: 3.3 mm

GENERAL NOTE: Column letters refer to D-90 subparagraphs. The units of measure are arbitrary but must be consistent.

is only necessary to record the data to obtain the length (3.3) and depth, (10% of t). The first, third, and sixth lines of the data tabulation are all that are necessary to define the through wall and length of the indication in this example.

APPENDIX E — COMPUTERIZED IMAGING TECHNIQUES

E-410 SCOPE

This Appendix provides requirements for computer imaging techniques.

E-420 GENERAL

Computerized imaging techniques (CITs) shall satisfy all of the basic instrument requirements described in T-431 and T-461. The search units used for CIT applications shall be characterized as specified in B-466. CITs shall be qualified in accordance with the requirements for flaw detection and/or sizing that are specified in the referencing Code Section.

The written procedure for CIT applications shall identify the specific test frequency and bandwidth to be utilized. In addition, such procedures shall define the signal processing techniques, shall include explicit guidelines for image interpretation, and shall identify the software code/program version to be used. This information shall also be included in the examination report. Each examination report shall document the specific scanning and imaging processes that were used so that these functions may be accurately repeated at a later time if necessary.

The computerized imaging process shall include a feature that generates a dimensional scale (in either two or three dimensions, as appropriate) to assist the operator in relating the imaged features to the actual, relevant dimensions of the component being examined. In addition, automated scaling factor indicators shall be integrally included to relate colors and/or image intensity to the relevant variable (i.e., signal amplitude, attenuation, etc.).

E-460 CALIBRATION

Calibration of computer imaging systems shall be conducted in such a manner that the gain levels are optimized for data acquisition and imaging purposes. The traditional DAC-based calibration process may also be required to establish specific scanning and/or flaw detection sensitivity levels.

For those CITs that employ signal processing to achieve image enhancement (SAFT-UT, L-SAFT, and broadband holography), at least one special lateral resolution and depth discrimination block for each specified examination shall be used in addition to the applicable calibration block required by Article 4. These blocks shall comply with J-431.

The block described in Fig. E-460.1 provides an effective resolution range for 45 deg and 60 deg search units and metal paths up to about 4 in. (100 mm). This is adequate for piping and similar components, but longer path lengths are required for reactor pressure vessels. A thicker block with the same sizes of flat-bottom holes, spacings, depths, and tolerances is required for metal paths greater than 4 in. (100 mm), and a 4 in. (100 mm) minimum distance between the edge of the holes and the edge of the block is required. These blocks provide a means for determining lateral resolution and depth discrimination of an ultrasonic imaging system.

Lateral resolution is defined as the minimum spacing between holes that can be resolved by the system. The holes are spaced such that the maximum separation between adjacent edges of successive holes is 1.000 in. (25.40 mm). The spacing progressively decreases by a factor of two between successive pairs of holes, and the minimum spacing is 0.015 in. (0.38 mm). Depth discrimination is demonstrated by observing the displayed metal paths (or the depths) of the various holes. Because the hole faces are not parallel to the scanning surface, each hole displays a range [about 0.1 in. (2.5 mm)] of metal paths. The "A" row has the shortest average metal path, the "C" row has the longest average metal path, and the "B" holes vary in average metal path.

Additional blocks are required to verify lateral resolution and depth discrimination when 0 deg longitudinal-wave examination is performed. Metal path lengths of 2 in. and 8 in. (50 mm and 200 mm), as appropriate, shall be provided as shown in Fig. E-460.2 for section thicknesses to 4 in. (100 mm), and a similar block with 8 in. (200 mm) metal paths is needed for section thicknesses over 4 in. (100 mm).

E-470 EXAMINATION

E-471 Synthetic Aperture Focusing Technique for Ultrasonic Testing (SAFT-UT)

The Synthetic Aperture Focusing Technique (SAFT) refers to a process in which the focal properties of a large-aperture focused search unit are synthetically generated from data collected while scanning over a large area using a small search unit with a divergent sound beam. The processing required to focus this collection of data

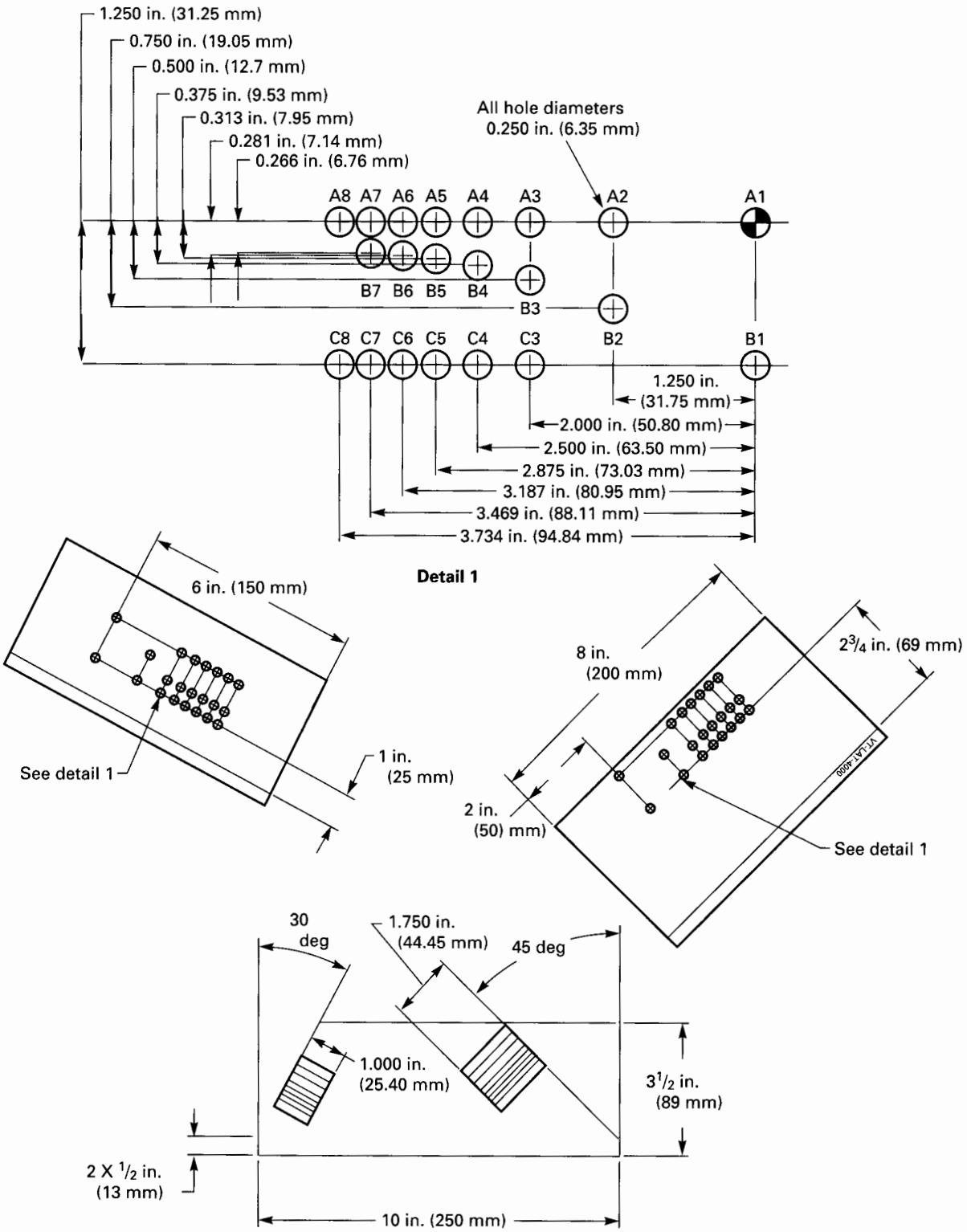


FIG. E-460.1 LATERAL RESOLUTION AND DEPTH DISCRIMINATION BLOCK FOR 45 deg AND 60 deg APPLICATIONS
(Not to Scale)

NOTES TO FIG. E-460.1:

GENERAL NOTES:

(a) View rotated for clarity.

(b) Insonification surface is shown at bottom.

(c) Tolerances: decimals: 0.XX = ± 0.03; 0.XXX = ± 0.005; angular: ± 1 deg.

(d) Hole identification:

(1) Engrave or stamp as shown with the characters upright when the large face of the block is up.

(2) Nominal character height is 0.25 in. (6 mm)

(3) Start numbering at the widest-spaced side.

(4) Label row of eight holes A1–A8.

(5) Label diagonal set of seven holes B1–B7.

(6) Label remaining six holes C3–C8.

(e) Hole spacing: minimum 0.010 in. (0.25 mm) material between hole edges.

(f) Hole depths: 30 deg. face: 1.000 in. (25.40 mm); 45 deg. face: 1.750 in. (44.45 mm)

(g) Drawing presentation: holes are shown from drilled face of block.

(h) Hole ends to be flat and parallel to drilled surface within 0.001 in. (0.03 mm) across face of hole.

(i) Maximum radius between side and face of hole is 0.005 in. (0.13 mm)

is a three-dimensional process called beam-forming, coherent summation, or synthetic aperture processing. The SAFT-UT process offers an inherent advantage over physical focusing processes because the resulting image is a full-volume, focused characterization of the material volume being examined. Traditional physical focusing processes provide focused data over only the depth of the focus zone of the transducer.

For the typical pulse-echo data collection scheme used with SAFT-UT, a focused search unit is positioned with the focal point located at the surface of the material under examination. This configuration produces a divergent ultrasonic beam in the material. Alternatively, a small-diameter contact search unit may be used to generate a divergent beam. As the search unit is scanned over the surface of the material, the A-scan record (RF waveform) is digitized for each position of the search unit. Any reflector present produces a collection of echoes in the A-scan records. For an elementary single-point reflector, the collection of echoes will form a hyperbolic surface within the data-set volume. The shape of the hyperboloid is determined by the depth of the reflector and the velocity of sound in the material. The relationship between echo location in the series of A-scans and the actual location of reflectors within the material makes it possible to reconstruct a high-resolution image that has a high signal-to-noise ratio. Two separate SAFT-UT configurations are possible: (a) the single-transducer, pulse-echo configuration; and (b) the dual-transducer, tandem configuration (TSAFT).

In general, the detected flaws may be categorized as volumetric, planar, or cracks. Flaw sizing is normally performed by measuring the vertical extent (cracks) or the cross-sectional distance (volumetric/planar) at the –6 dB levels once the flaw has been isolated and the image normalized to the maximum value of the flaw. Multiple images are often required to adequately categorize (classify) the flaw and to characterize the actual flaw shape and size. Tandem sizing and analysis uses similar techniques to pulse-echo, but provides images that may be easier to interpret.

The location of indications within the image space is influenced by material thickness, velocity, and refracted angle of the UT beam. The SAFT algorithm assumes isotropic and homogeneous material; i.e., the SAFT algorithm requires (for optimum performance) that the acoustic velocity be accurately known and constant throughout the material volume.

Lateral resolution is the ability of the SAFT-UT system to distinguish between two objects in an x-y plane that is perpendicular to the axis of the sound beam. Lateral resolution is measured by determining the minimum spacing between pairs of holes that are clearly separated in the image. A pair of holes is considered separated if the signal amplitude in the image decreases by at least 6 dB between the peak signals of two holes.

Depth resolution is the ability of a SAFT-UT system to distinguish between the depth of two holes whose axes are parallel to the major axis of the sound beam. Depth resolution is measured by determining the minimum difference in depth between two holes.

The lateral resolution for a SAFT-UT system is typically 1.5 wavelengths (or better) for examination of wrought ferritic components, and 2.0 wavelengths (or better) for examination of wrought stainless steel components. The depth resolution for these same materials will typically be 0.25 wavelengths (or better).

E-472 Line-Synthetic Aperture Focusing Technique (L-SAFT)

The Line Synthetic Aperture Focusing Technique (L-SAFT) is useful for analyzing detected indications. L-SAFT is a two-dimensional process in which the focal properties of a large-aperture, linearly focused search unit

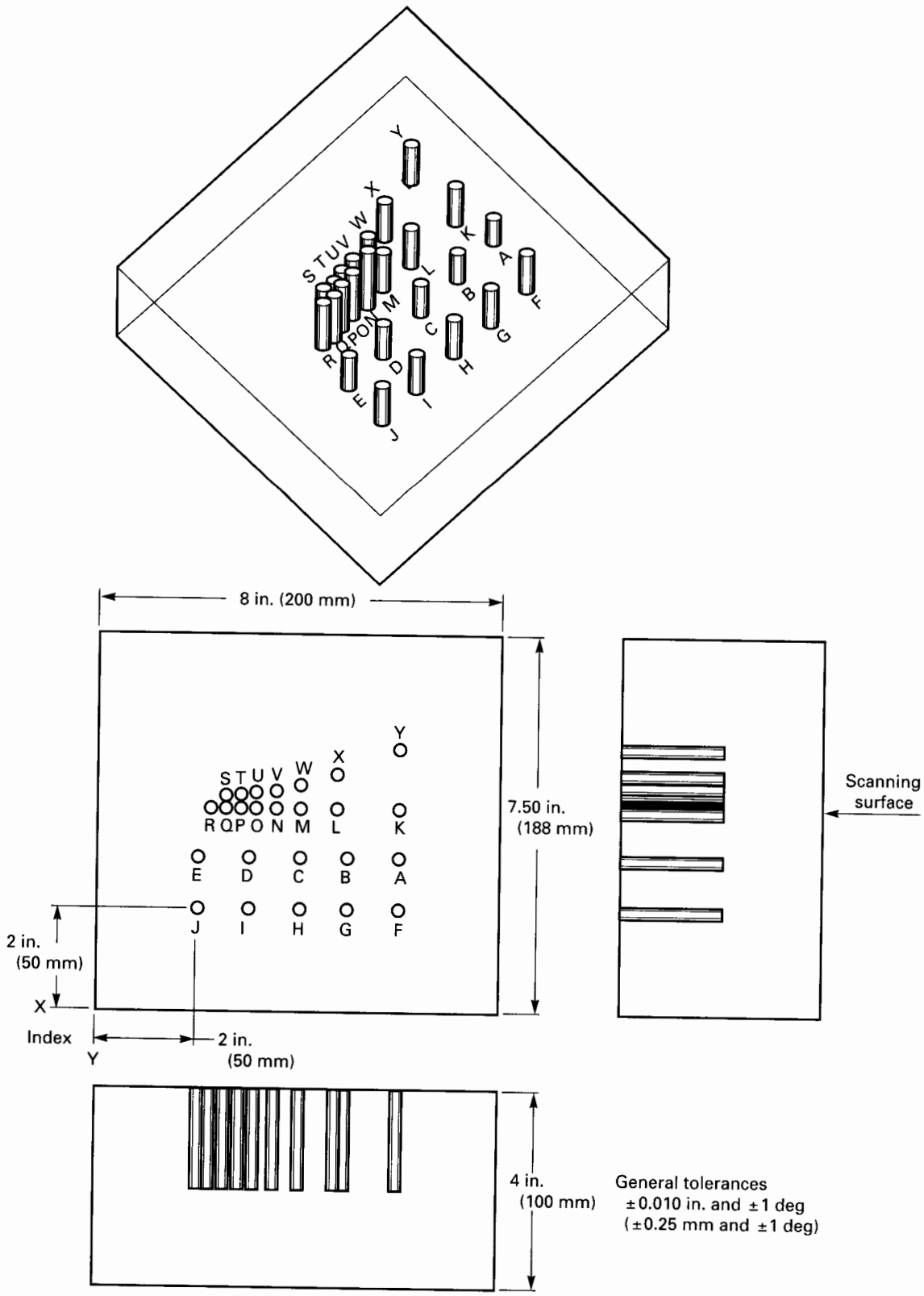


FIG. E-460.2 LATERAL AND DEPTH RESOLUTION BLOCK FOR 0 deg APPLICATIONS

are synthetically generated from data collected over a scan line using a small search unit with a diverging sound beam. The processing required to impose a focusing effect of the acquired data is also called synthetic aperture processing. The L-SAFT system can be operated like conventional UT equipment for data recording. It will function with either single- or dual-element transducers.

Analysis measurements, in general, are performed to determine flaw size, volume, location, and configuration. To decide if the flaw is a crack or volumetric, the crack-tip-diffraction response offers one criterion, and the superimposed image of two measurements made using different directions of incidence offers another.

All constraints for SAFT-UT apply to L-SAFT and vice versa. The difference between L-SAFT and SAFT-UT is that SAFT-UT provides a higher resolution image than can be obtained with L-SAFT.

E-473 Broadband Holography Technique

The holography technique produces an object image by calculation based on data from a diffraction pattern. If the result is a two-dimensional image and the data are acquired along one scan, the process is called "line-holography." If the result is a two-dimensional image based upon an area scanned, then it is called "holography." For the special case of applying holography principles to ultrasonic testing, the image of flaws (in more than one dimension) can be obtained by recording the amplitude, phase, and time-of-flight data from the scanned volume. The holography process offers a unique feature because the resulting image is a one- or two-dimensional characterization of the material.

This technique provides good resolution in the axial direction by using broadband search units. These search units transmit a very short pulse, and therefore the axial resolution is improved. The maximum bandwidth may be 20 MHz without using filtering, and up to 8 MHz using an integrated filter.

Analysis measurements, in general, are performed to obtain information on size, volume, location, and configuration of detected flaws. The results of the holography-measurements per scan line show a two-dimensional image of the flaw by color-coded display. The size of flaws can be determined by using the 6 dB drop in the color code. More information on the flaw dimensions is obtained by scans in different directions (i.e., parallel, perpendicular) at different angles of incidence. To decide if the flaw is a crack or a volumetric flaw, the crack tip technique offers one criterion and comparison of two measurements from different directions of incidence offers another. Measurement results obtained by imaging techniques always require specific interpretation. Small variations in material thickness, sound velocity, or refracted beam angle may influence the reconstruction results. The holography processing calculations also assume that the velocity is accurately known and constant throughout the material.

E-474 UT-Phased Array Technique

The UT-Phased Array Technique is a process wherein UT data are generated by controlled incremental variation of the ultrasonic beam angle in the azimuthal or lateral direction while scanning the object under examination. This process offers an advantage over processes using conventional search units with fixed beam angles because it acquires considerably more information about the reflecting object by using more aspect angles in direct impingement.

Each phased array search unit consists of a series of individually wired transducer elements on a wedge that are activated separately using a pre-selectable time delay pattern. With a linear delay time between the transmitter pulses, an inclined sound field is generated. Varying the angle of refraction requires a variation of the linear distribution of the delay time. Depending on the search unit design, it is possible to electronically vary either the angle of incidence or the lateral/skew angle. In the receiving mode, acoustic energy is received by the elements and the signals undergo a summation process utilizing the same time delay pattern as was used during transmission.

Flaw sizing is normally performed by measuring the vertical extent (in the case of cracks) or the cross-sectional distance (in the case of volumetric/planar flaws) at the 6 dB levels once the flaw has been isolated and the image normalized. Tandem sizing and analysis uses techniques similar to pulse-echo but provides images that are easier to interpret since specular reflection is used for defects oriented perpendicular to the surface. For cracks and planar defects, the result should be verified using crack-tip-diffraction signals from the upper and lower ends of the flaw, since the phased array approach with tomographic reconstruction is most sensitive to flaw tip indications and is able to give a clear reconstruction image of these refraction phenomena. As with other techniques, the phased array process assumes isotropic and homogeneous material whose acoustic velocity is constant and accurately known.

E-475 UT-Amplitude Time-Of-Flight Locus-Curve Analysis Technique

The UT-amplitude time-of-flight locus-curve analysis technique utilizes multiple search units in pulse-echo, transmitter-receiver, or tandem configuration. Individually selectable parameters control the compression of the

A-scan information using a pattern-recognition algorithm, so that only the relevant A-scan amplitudes are stored and further processed.

The parameter values in the A-scan compression algorithm determine how many pre-cursing and how many post-cursing half-wave peaks must be smaller than a specific amplitude, so that this largest amplitude is identified as as relevant signal. These raw data can be displayed in B-, C-, and D-scan (side, top, and end view) presentations, with selectable color-code increments for amplitude and fast zoom capabilities. This operating mode is most suitable for detection purposes. For discrimination, a two-dimensional spatial-filtering algorithm is applied to search for correlation of the time-of-flight raw data with reflector-typical time-of-flight trajectories.

Tandem sizing and analysis uses techniques similar to pulse-echo but provides images that may be easier to interpret since the specular reflections from flaws oriented perpendicular to the surface are used. For cracks and planar flaws, the results should be verified with crack-tip-diffraction signals from the upper and lower end of the flaw since the acoustic parameters are very sensitive to flaw tip indications and a clear reconstruction image of these refraction phenomena is possible with this technique.

The location of indications within the image space is influenced by material thickness and actual sound velocity (i.e., isotropic and homogeneous material is assumed). However, deteriorating influences from anisotropic material (such as cladding) can be reduced by appropriate selection of the search unit parameters.

E-476 Automated Data Acquisition and Imaging Technique

Automated data acquisition and imaging is a multichannel technique that may be used for acquisition and analysis of UT data for both contact and immersion applications. This technique allows interfacing between the calibration, acquisition, and analysis modes; and for assignment of specific examination configurations. This technique utilizes a real-time display for monitoring the quality of data being collected, and provides for display of specific amplitude ranges and the capability to analyze peak data through target motion filtering. A cursor function allows scanning the RF data one waveform at a time to aid in crack sizing using tip-diffraction. For both peak and RF data, the technique can collect, display, and analyze data for scanning in either the axial or circumferential directions.

This technique facilitates detection and sizing of both volumetric and planar flaws. For sizing volumetric flaws, amplitude-based methods may be used; and for sizing planar flaws, the crack-tip-diffraction method may be used. An overlay feature allows the analyst to generate a composite image using several sets of ultrasonic data. All data displayed in the analyze mode may be displayed with respect to the physical coordinates of the component.

APPENDIX F DELETED A05

APPENDIX G — ALTERNATE CALIBRATION BLOCK CONFIGURATION

G-410 SCOPE

This Appendix provides guidance for using flat basic calibration blocks of various thicknesses to calibrate the examination of convex surface materials greater than 20 in. (500 mm) in diameter. An adjustment of receiver gain may be required when flat calibration blocks are used. The gain corrections apply to the far field portion of the sound beam.

G-460 CALIBRATION

G-461 Determination of Gain Correction

To determine the required increase in gain, the ratio of the material radius, R, to the critical radius of the transducer, R_c, must be evaluated as follows.

(a) When the ratio of R/R_c, the radius of curvature of the material R divided by the critical radius of the transducer R_c from Table G-461 and Fig. G-461(a), is equal to or greater than 1.0, no gain correction is required.

TABLE G-461
TRANSDUCER FACTOR F_1 FOR VARIOUS ULTRASONIC TRANSDUCER DIAMETERS AND FREQUENCIES

U.S. Customary Units

Frequency MHz	Transducer Diameters, in. 0.25	0.5	0.75	1.0	1.125
	F_1, in.				
1.0	2.58	10.3	23.2	41.3	52.3
2.25	5.81	23.2	52.2	92.9	118
5.0	12.9	51.2	116	207	262
10.0	25.8	103	232	413	523

SI Units

Frequency MHz	Transducer Diameters, mm 6.4	13	19	25	29
	F_1, mm				
1.0	65.5	262	590	1 049	1 328
2.25	148	590	1 327	2 360	2 987
5.0	328	1 314	2 958	5 258	6 655
10.0	655	2 622	5 900	10 490	13 276

(b) When the ratio of R/R_c is less than 1.0, the gain correction must be obtained from Fig. G-461(b).

(c) Example. Material with a 10 in. (250 mm) radius (R) will be examined with a 1 in. (25 mm) diameter 2.25 MHz boron carbide faced search unit using glycerine as a couplant.

(1) Determine the appropriate transducer factor, F_1 from Table G-461; $F_1 = 92.9$.

(2) Determine the R_c from Fig. G-461(a); $R_c = 100$ in. (2 500 mm).

(3) Calculate the R/R_c ratio; 10 in./100 in. = 0.1 (250 mm/2 500 mm = 0.1).

(4) Using Fig. G-461(b), obtain the gain increase required; 12 dB.

This gain increase calibrates the examination on the curved surface after establishing calibration sensitivity on a flat calibration block.

APPENDIX H — RECORDING ANGLE BEAM EXAMINATION DATA FOR PLANAR REFLECTORS

H-410 SCOPE

This Appendix describes a method for recording angle beam examination data for planar reflectors when amplitude based dimensioning is to be performed.

H-490 RECORDS/DOCUMENTATION

(a) Record all reflectors that produce a response equal to or greater than 20% of the distance-amplitude correction (DAC). However, the clad interface metallurgical reflectors and back wall reflections need not be recorded. Record surface reflectors that produce a response equal to or exceeding the calibration amplitude established per T-463.1.3(c). Record all search unit position and location dimensions to the nearest tenth of an inch.

(b) Obtain data from successive scans at increments no greater than nine-tenths of the transducer dimension measured parallel to the scan increment change (10% overlap). Record data for the end points as determined by 20% of DAC. Emphasis must be placed on measurement of the parameters determining the reflector length and height and the distances from the examination surface to the top and bottom of the reflector, since these dimensions are the factors most critical in determining ultimate evaluation and disposition of the flaw (see Appendix D for an illustrated example).

(c) The following reflector data shall be recorded when a reflector exceeds 20% DAC.

(1) Maximum percent of DAC, sweep reading of indication, search unit position, location along the length of the weld, and beam direction.

(2) Through-Wall Dimension

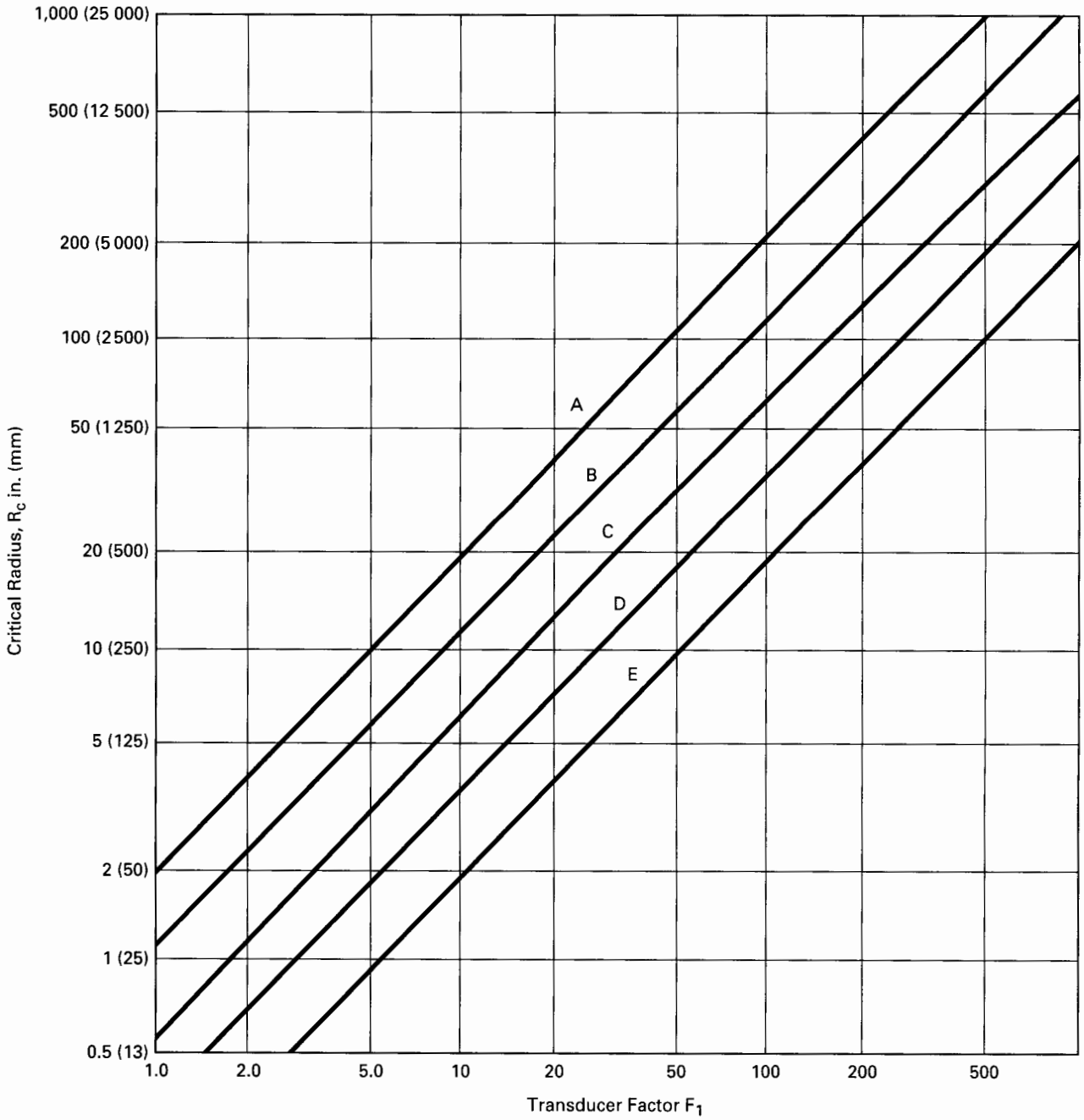
(a) For reflectors 20% to 100% DAC, the minimum sweep reading and its position and location along the length of the reflector for 20% DAC when approaching the reflector from the maximum signal direction.

(b) For reflectors 20% to 100% DAC, the maximum sweep reading and its position and location along the length of the reflector for 20% DAC when moving away from the reflector's maximum signal direction.

(c) For reflectors exceeding 100% DAC, minimum sweep reading and its position and location along the length of the reflector for 50% of the maximum amplitude when approaching the reflector from the maximum signal direction.

(d) For reflectors exceeding 100% DAC, maximum sweep reading and its position and location along the length of the reflector for 50% of the maximum amplitude when moving away from the reflector's maximum signal direction.

(3) Length Dimension. The length of the reflector shall be obtained by recording the position and location along the length of weld as determined by 20% of DAC for each end of the reflector.



Curve	Couplant	Transducer Wearface
A	Motor oil or water	Aluminum Oxide or Boron Carbide
B	Motor oil or water	Quartz
	Glycerine or syn. ester	Aluminum Oxide or Boron Carbide
C	Glycerine or syn. ester	Quartz
D	Motor oil or water	Plastic
E	Glycerine or syn. ester	Plastic

FIG. G-461(a) CRITICAL RADIUS R_C FOR TRANSDUCER/COUPLANT COMBINATIONS

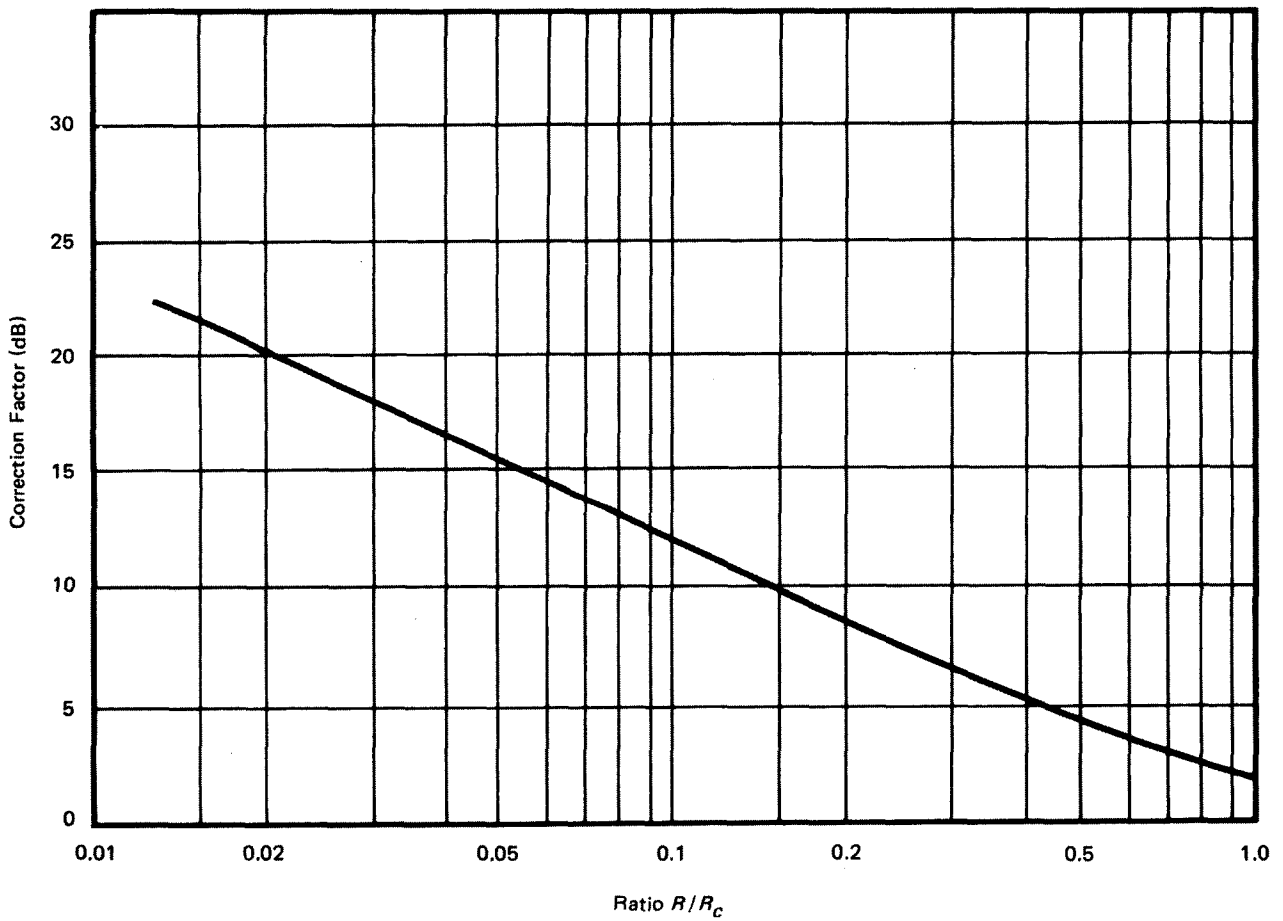


FIG. G-461(b) CORRECTION FACTOR (GAIN) FOR VARIOUS ULTRASONIC EXAMINATION PARAMETERS

APPENDIX I — EXAMINATION OF WELDS USING ANGLE BEAM SEARCH UNITS

I-410 SCOPE

This Appendix describes a method of examination of welds using angle beam search units.

I-470 EXAMINATION

I-471 General Scanning Requirements

Three angle beams, having nominal angles of 45 deg, 60 deg, and 70 deg (with respect to a perpendicular to the examination surface), shall generally be used. Beam angles other than 45 deg and 60 deg are permitted provided the measured difference between angles is at least 10 deg. Additional ¼ volume angle beam examination shall be conducted on the material volume within ¼ of the thickness adjacent to the examination surface. Single or dual element longitudinal or shear wave angle beams in the range of 60 deg through 70 deg (with respect to perpendicular to the examination surface) shall be used in this ¼ volume.

I-472 Exceptions To General Scanning Requirements

Other angles may be used for examination of:

(a) flange welds, when the examination is conducted from the flange face;

(b) nozzles and nozzle welds, when the examination is conducted from the nozzle bore;

(c) attachment and support welds;

(d) examination of double taper junctures.

I-473 Examination Coverage

Each pass of the search unit shall overlap a minimum of 50% of the active transducer (piezoelectric element) dimension perpendicular to the direction of the scan.

APPENDIX J — ALTERNATIVE BASIC CALIBRATION BLOCK

J-410 SCOPE

This Appendix contains the description for an alternative to Article 4, T-434.2 for basic calibration blocks used for distance-amplitude correction (DAC) calibration techniques.

J-430 EQUIPMENT

J-431 Basic Calibration Block

The basic calibration block(s) containing basic calibration reflectors to establish a primary reference response of the equipment and to construct a distance-amplitude correction curve shall be as shown in Fig. J-431. The basic calibration reflectors shall be located either in the component material or in a basic calibration block.

J-432 Basic Calibration Block Material

(a) Block Selection. The material from which the block is fabricated shall be from one of the following:

(1) nozzle dropout from the component;

(2) a component prolongation;

(3) material of the same material specification, product form, and heat treatment condition as the material to which the search unit is applied during the examination.

(b) Clad. Where the component material is clad and the cladding is a factor during examination, the block shall be clad to the component clad nominal thickness $\pm 1/8$ in. (3 mm). Deposition of clad shall be by the same method (i.e., rollbonded, manual weld deposited, automatic wire deposited, or automatic strip deposited) as used to clad the component to be examined. When the cladding method is not known or the method of cladding used on the component is impractical for block cladding, deposition of clad may be by the manual method. When the parent materials on opposite sides of a weld are clad by different methods, the cladding on the calibration block shall be applied by the method used on the side of the weld from which the examination will be conducted. When the examination is conducted from both sides, the calibration block shall provide for calibration for both methods of cladding.

(c) Heat Treatment. The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade and a postweld heat treatment of at least 2 hr.

(d) Surface Finish. The finish on the surfaces of the block shall be representative of the surface finishes of the component.

(e) Block Quality. The calibration block material shall be completely examined with a straight beam search unit. Areas that contain indications exceeding the remaining back reflection shall be excluded from the beam paths required to reach the various calibration reflectors.

J-433 Calibration Reflectors

(a) Basic Calibration Reflectors. The side of a hole drilled with its axis parallel to the examination surface is the basic calibration reflector. A square notch shall also be used. The reflecting surface of the notches shall be perpendicular to the block surface. See Fig. J-431.

(b) Scribe Line. A scribe line as shown in Fig. J-431 shall be made in the thickness direction through the in-line hole center lines and continued across the two examination surfaces of the block.

(c) Additional Reflectors. Additional reflectors may be installed; these reflectors shall not interfere with establishing the primary reference.

(d) Basic Calibration Block Configuration. Figure J-431 shows block configuration with hole size and location. Each weld thickness on the component must be represented by a block having a thickness relative to the component weld as shown in Fig. J-431. Where the block thickness ±1 in. (25 mm) spans two of the weld thickness ranges shown in Fig. J-431, the block's use shall be acceptable in those portions of each thickness range covered by 1 in. (25 mm). The holes shall be in accordance with the thickness of the block. Where two or more base material thicknesses are involved, the calibration block thickness shall be sufficient to contain the entire examination beam path.

(e) Welds in Materials With Diameters Greater Than 20 in. (500 mm). For examination of welds in materials where the examination surface diameter is greater than 20 in. (500 mm), a single curved basic calibration block may be used to calibrate the straight and angle beam examinations on surfaces in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. Alternatively, a flat basic calibration block may be used provided the minimum convex, concave, or compound curvature radius to be examined is greater than the critical radius determined by Appendix A. For the purpose of this determination, the dimension of the straight or angle beam search units flat contact surface tangent to the minimum radius shall be used instead of the transducer diameter in Table A-10.

(f) Welds in Materials With Diameters 20 in. (500 mm) and Less. The basic calibration block shall be curved for welds in materials with diameters 20 in. (500 mm) and less. A single curved basic calibration block may be used to calibrate the examination on surfaces in the range of

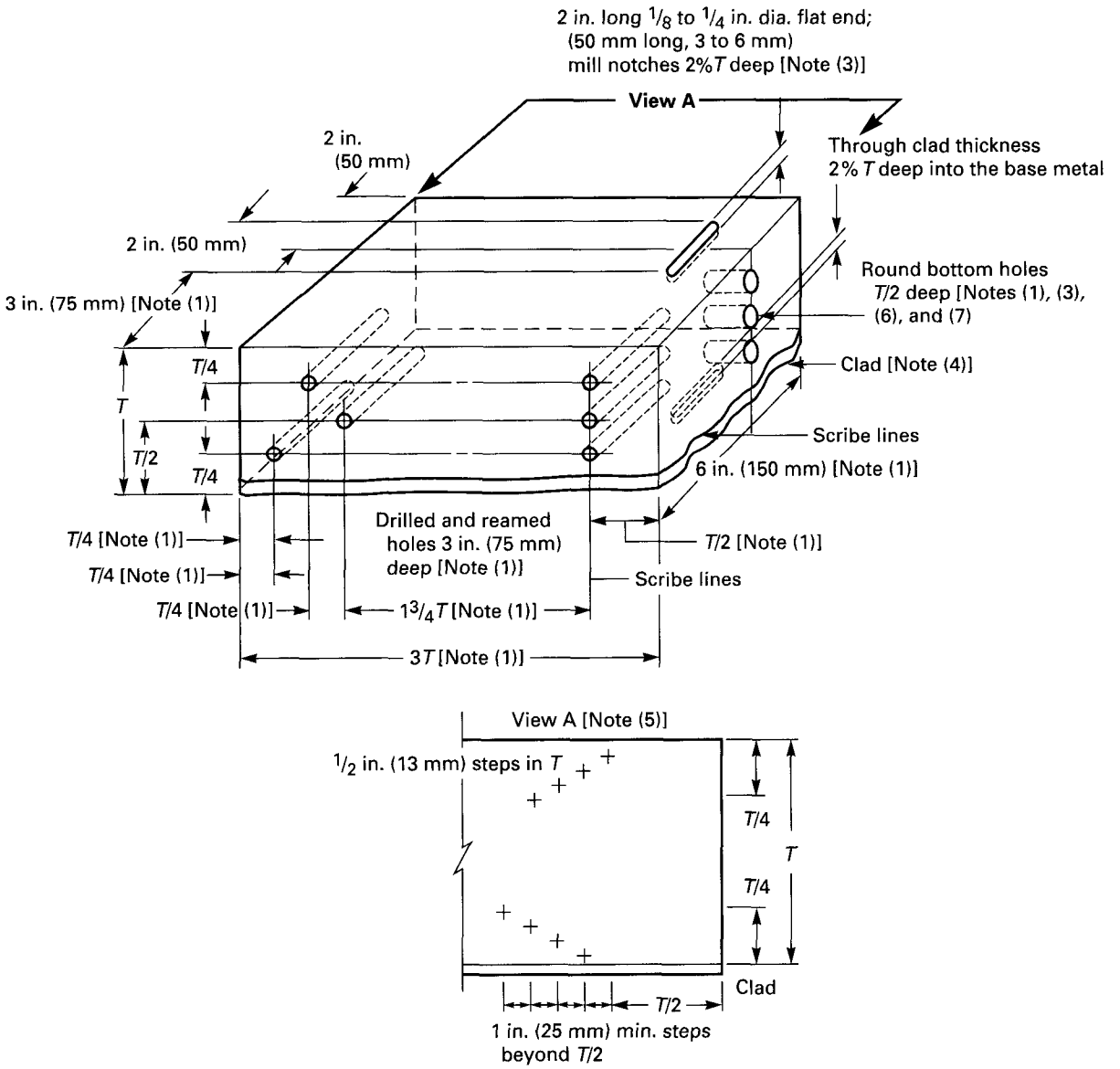


FIG. J-431 BASIC CALIBRATION BLOCK

curvature from 0.9 to 1.5 times the basic calibration block diameter. For example, an 8 in. (200 mm) diameter curved block may be used to calibrate the examination on surfaces in the range of curvature from 7.2 in. to 12 in. (180 mm to 300 mm) diameter. The curvature range from 0.94 in. to 20 in. (24 mm to 500 mm) diameter requires six block curvatures as indicated in Fig. T-434.1.7.2 for any thickness range as indicated in Fig. J-431.

(g) Retention and Control. All basic calibration blocks for the examination shall meet the retention and control requirements of the referencing Code Section.

APPENDIX K — RECORDING STRAIGHT BEAM EXAMINATION DATA FOR PLANAR REFLECTORS

K-410 SCOPE

This Appendix describes a method for recording straight beam examination data for planar reflectors when amplitude based dimensioning is to be performed.

NOTES TO FIG. J-431:

Weld Thickness t, in. (mm)	Basic Calibration Block Thickness T, in. (mm)	Side Drilled Hole Diameter, in. (mm) [Note (3)]	Round Bottom Hole Diameter, in. (mm) [Notes (3) and (6)]
Over 2 through 4 (50 through 100)	3 or t (75 or t)	3/16 (5)	3/8 (10)
Over 4 through 6 (100 through 150)	5 or t (125 or t)	1/4 (6)	7/16 (11)
Over 6 through 8 (150 through 200)	7 or t (175 or t)	5/16 (8)	1/2 (13)
Over 8 through 10 (200 through 250)	9 or t (225 or t)	3/8 (10)	9/16 (14)
Over 10 through 12 (250 through 300)	11 or t (275 or t)	7/16 (11)	5/8 (16)
Over 12 through 14 (300 through 350)	13 or t (325 or t)	1/2 (13)	11/16 (17)
Over 14 (350)	$t \pm 1$ ($t \pm 25$)	[Note (2)]	[Note (2)]

NOTES:

(1) Minimum dimensions.

(2) For each increase in weld thickness of 2 in. (50 mm) or fraction thereof over 14 in. (356 mm), the hole diameter shall increase 1/16 in. (1.5 mm).

(3) The tolerances for the hole diameters shall be ± 1/32 in. (0.8 mm); tolerances on notch depth shall be + 10 and − 20% (need only be held at the thinnest clad thickness along the reflecting surface of the notch); tolerance on hole location through the thickness shall be ± 1/8 in. (3 mm); perpendicular tolerances on notch reflecting surface shall be ± 2 deg; tolerance on notch length shall be ± 1/4 in. (± 6 mm).

(4) Clad shall not be included in T.

(5) Subsurface calibration holes 1/8 in. (3 mm) (maximum) diameter by 1 1/2 in. (38 mm) deep (minimum) shall be drilled at the clad-to-base metal interface and at 1/2 in. (13 mm) increments through T/4 from the clad surface, also at 1/2 in. (13 mm) from the unclad surface and at 1/2 in. (13 mm) increments through T/4 from the unclad surface. In each case, the hole nearest the surface shall be drilled at T/2 from the edge of the block. Holes at 1/2 in. (13 mm) thickness increments from the near surface hole shall be drilled at 1 in. (25 mm) minimum intervals from T/2.

(6) Round (hemispherical) bottom holes shall be drilled only when required by a Referencing Code Section for beam spread measurements (see T-434.1) and the technique of B-60 is used. The round bottom holes may be located in the largest block in a set of basic calibration blocks, or in a separate block representing the maximum thickness to be examined.

(7) T/2 hole may be located in the opposite end of the block.

K-470 EXAMINATION

K-471 Overlap

Obtain data from successive scans at increments no greater than nine-tenths of the transducer dimension measured parallel to the scan increment change (10% overlap). Record data for the end points as determined by 50% of DAC.

K-490 RECORDS/DOCUMENTATION

Record all reflectors that produce a response equal to or greater than 50% of the distance-amplitude correction (DAC). However, clad interface and back wall reflections need not be recorded. Record all search unit position and location dimensions to the nearest tenth of an inch.

APPENDIX L — TOFD SIZING DEMONSTRATION/DUAL PROBE — COMPUTER IMAGING TECHNIQUE

L-410 SCOPE

This Appendix provides a methodology that can be used to demonstrate a UT system's ability to accurately determine the depth and length of surface machined notches originating on the examination surface from the resulting diffracted signals when a nonamplitude, Time-of-Flight-Diffraction (TOFD), dual probe, computer imaging technique (CIT) is utilized and includes a flaw classification/sizing system.

L-420 GENERAL

Article 4 requirements apply except as modified herein.

L-430 EQUIPMENT

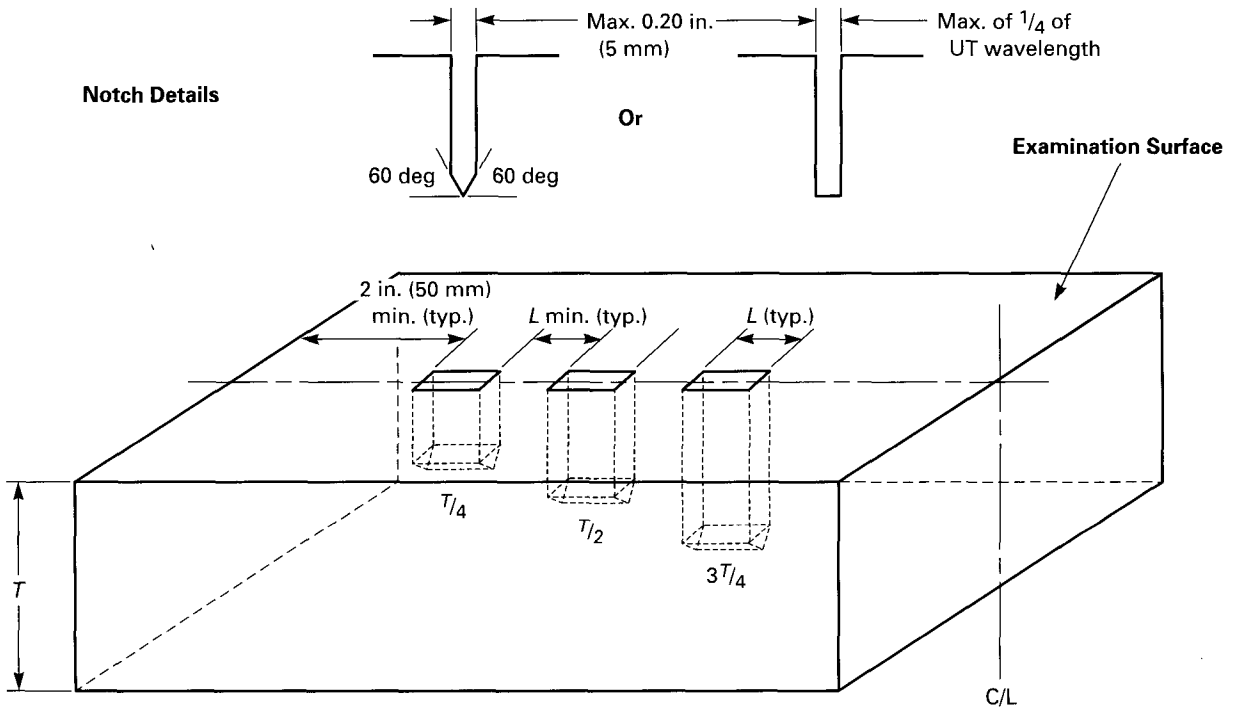
L-431 System

System equipment [e.g., UT unit, computer, software, scanner(s), search unit(s), cable(s), couplant, encoder(s), etc.] shall be described in the written procedure.

L-432 Demonstration Block

(a) The block material and shape (flat or curved) shall be the same as that desired to demonstrate the system's accuracy.

(b) The block shall contain a minimum of three notches machined to depths of T/4, T/2, and 3T/4 and with lengths (L) and, if applicable, orientation as that



GENERAL NOTE: Block length and width to be adequate for UT System Scanner.

FIG. L-432 EXAMPLE OF A FLAT DEMONSTRATION BLOCK CONTAINING THREE NOTCHES

desired to demonstrate the system's sizing accuracy. See Fig. L-432 for an example.

Additional notches may be necessary depending on:

(1) the thickness of the block;

(2) the number of examination zones the block thickness is divided into;

(3) whether or not the zones are of equal thickness (for example: three zones could be broken into a top 1/3, middle 1/3, and bottom 1/3 vs. top 1/4, middle 1/2, and bottom 1/4); and

(4) the depths desired to be demonstrated.

(c) Prior to machining the notches, the block material through which the sound paths must travel shall be examined with the system equipment to ensure that it contains no reflectors that will interfere with the demonstration.

L-460 CALIBRATION

L-461 System

The system shall be calibrated per the procedure to be demonstrated.

L-462 System Checks

The following checks shall be performed prior to the demonstration:

(a) Positional Encoder Check. The positional encoder shall be moved through a measured distance of 20 in. (500 mm). The system read-out shall be within ±1% [±0.2 in. (5 mm)] of the measured distance. Encoders failing this check shall be re-calibrated and this check repeated.

(b) Thickness Check. A free-run shall be made on the measuring block. The distance between the lateral wave and first back-wall signal shall be within ±0.02 in. (0.5 mm) of the block's measured thickness. Set-ups failing this check shall have the probe separation distance either adjusted or its programmed value changed and this check repeated.

L-470 EXAMINATION

The demonstration block shall be scanned per the procedure and the data recorded.

Demonstrations may be performed utilizing:

(a) D-scan (non-parallel scan) techniques

(b) B-scan (parallel scan) techniques

(c) D-scan (non-parallel scan) techniques with the notches offset by varying amounts to either side of being centered.

L-480 EVALUATION

L-481 Sizing Determinations

The depth of the notches from the scanning surface and their length shall be determined per the procedure to be demonstrated.

L-482 Sizing Accuracy Determinations

Sizing accuracy (%) shall be determined by the following formulas:

(a) Depth:

$$\frac{D_d - D_m}{D_m} \times 100$$

(b) Length:

$$\frac{L_d - L_m}{L_m} \times 100$$

where:

D_d and L_d are the notches' depth and lengths, respectively, as determined by the UT system being demonstrated, and

D_m and L_m are the notches' depth and lengths, respectively, as determined by physical measurement (i.e., such as replication)

NOTE: Use consistent units.

L-483 Classification/Sizing System

L-483.1 Sizing. Flaws shall be classified as follows:

(a) Top-Surface Connected Flaws. Flaw indications consisting solely of a lower-tip diffracted signal and with an associated weakening, shift, or interruption of the lateral wave signal, shall be considered as extending to the top-surface unless further evaluated by other NDE methods.

(b) Embedded Flaws. Flaw indications with both an upper and lower-tip diffracted signal or solely an upper-tip diffracted signal and with no associated weakening, shift, or interruption of the back-wall signal shall be considered embedded.

(c) Bottom-Surface Connected Flaws. Flaw indications consisting solely of an upper-tip diffracted signal and with an associated shift of the backwall or interruption of the back-wall signal, shall be considered as extending to the bottom surface unless further evaluated by other NDE methods.

L-483.2 Flaw Height Determination. Flaw height (thru-wall dimension) shall be determined as follows:

(a) Top-Surface Connected Flaws. The height of a top-surface connected flaw shall be determined by the distance between the top-surface lateral wave and the lower-tip diffracted signal.

(b) Embedded Flaws. The height (h) of an embedded flaw shall be determined by:

(1) the distance between the upper-tip diffracted signal and the lower-tip diffracted signal or,

(2) the following calculation for flaws with just a singular upper-tip diffracted signal:

$$h = [\,(\,c\,(\,t_d + t_p\,)/2\,)^2 - s^2\,)\,]^{1/2} - d$$

where:

c = longitudinal sound velocity
s = half the distance between the two probes' index points
t_d = the time-of-flight at depth d
t_p = the length of the acoustic pulse
d = depth of the flaw below the scanning surface

NOTE: Use consistent units.

(c) Bottom-Surface Connected Flaws. The height of a bottom-surface connected flaw shall be determined by the distance between the upper-tip diffracted signal and the back-wall signal.

L-483.3 Flaw Length Determination. The flaw length shall be determined by the distance between end fitting hyperbolic cursurs or the flaw end points after a synthetic aperture focusing technique (SAFT) program has been run on the data.

L-490 DOCUMENTATION

L-491 Demonstration Report

In addition to the applicable items in T-492, the report of demonstration shall contain the following information:

(a) computerized program identification and revision;

(b) mode(s) of wave propagation used;

(c) demonstration block configuration (material, thickness, and curvature);

(d) notch depths, lengths, and, if applicable, orientation (i.e., axial or circumferential);

(e) instrument settings and scanning data;

(f) accuracy results.

APPENDIX M — GENERAL TECHNIQUES FOR ANGLE BEAM LONGITUDINAL WAVE CALIBRATIONS A05

M-410 SCOPE

This Appendix provides general techniques for angle beam longitudinal wave calibration. Other techniques

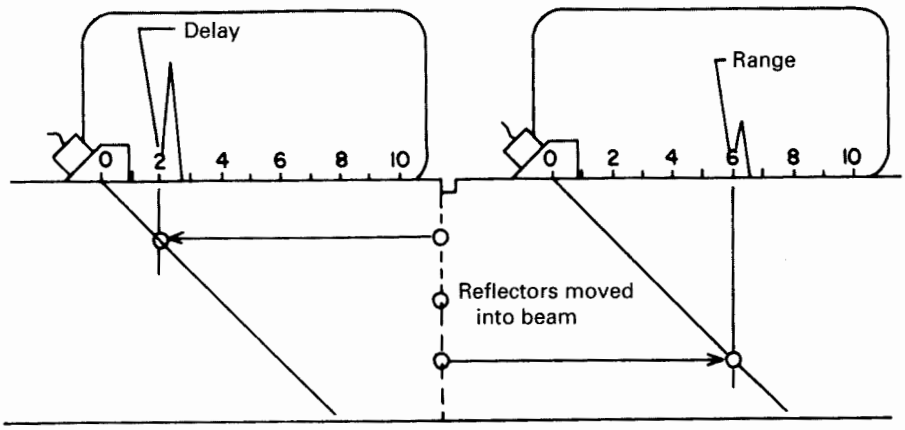


FIG. M-461.1 SWEEP RANGE (SIDE DRILLED HOLES)

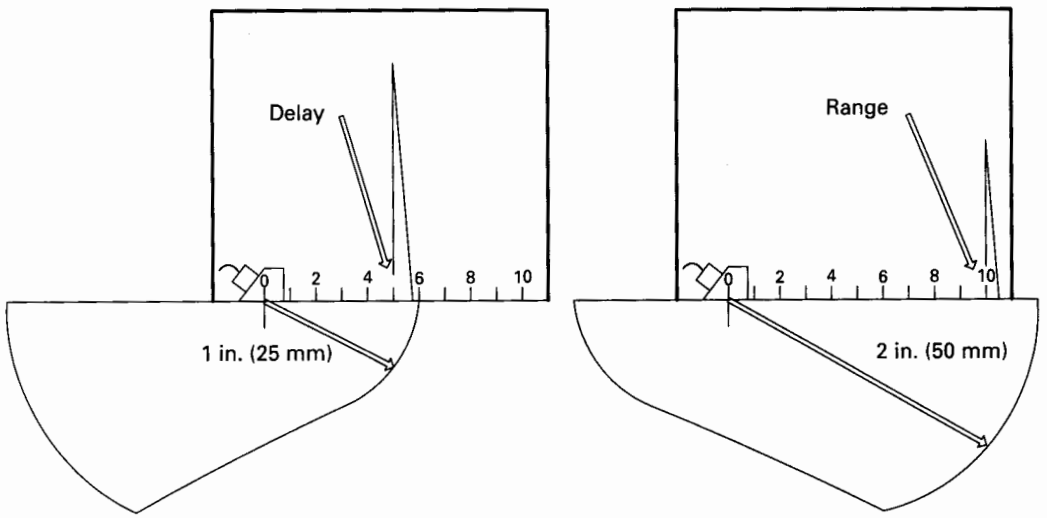


FIG. M-461.2 SWEEP RANGE (CYLINDRICAL SURFACES)

may be used. The sweep range may be calibrated in terms of metal path, projected surface distance, or actual depth to the reflector. The particular method may be selected according to the preference of the examiner.

Angle beam longitudinal wave search units are normally limited to ½V-path calibrations, since there is a substantial loss in beam energy upon reflection due to mode conversion.

M-460 CALIBRATION

M-461 Sweep Range Calibration

M-461.1 Side-Drilled Holes (See Fig. M-461.1)

NOTE: This technique provides sweep calibration for depth.

M-461.1.1 Delay Control Adjustment. Position the search unit for the maximum indication from the ¼T side-drilled hole (SDH). Adjust the left edge of this indication to line 2 on the screen with the delay control.

M-461.1.2 Range[6] Control Adjustment. Position the search unit for the maximum indication from the ¾T SDH. Adjust the left edge of this indication to line 6 on the screen with the range control.

M-461.1.3 Repeat Adjustments. Repeat delay and range adjustments until the ¼T and ¾T SDH indications start at sweep lines 2 and 6.

M-461.1.4 Sweep Readings. Two divisions on the sweep now equal ¼T.

M-461.2 Cylindrical Surface Reference Blocks (See Fig. M-461.2)

[6] *Range* has been replaced on many new instruments with *velocity*.

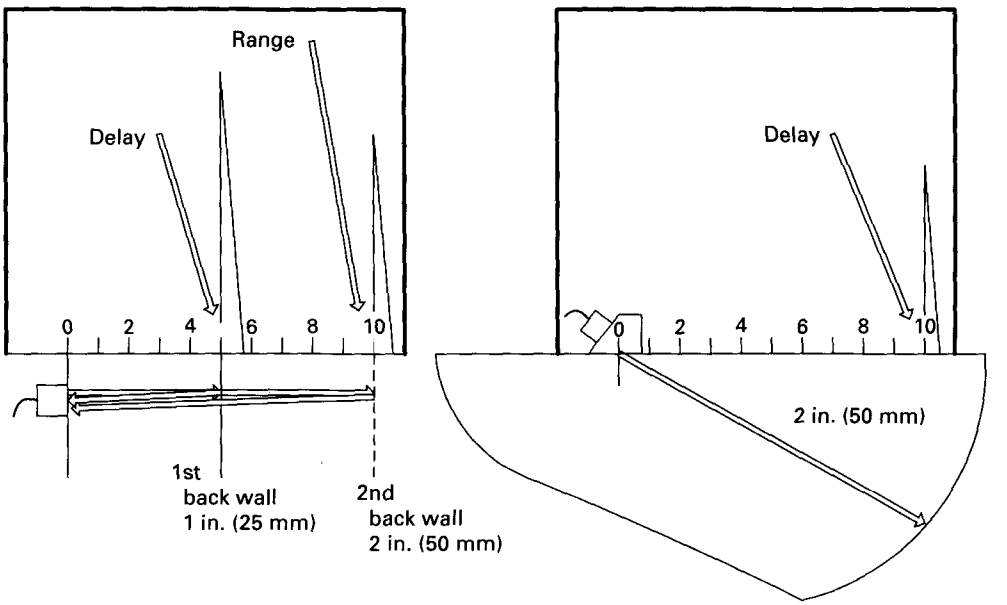


FIG. M-461.3 SWEEP RANGE (STRAIGHT BEAM SEARCH UNIT)

NOTE: This technique provides sweep calibration for metal path.

M-461.2.1 Delay Control Adjustment. Position the search unit for the maximum indication from the 1 in. (25 mm) cylindrical surface. Adjust the left edge of this indication to line 5 on the screen with the delay control.

M-461.2.2 Range Control Adjustment. Position the search unit for the maximum indication from the 2 in. (50 mm) cylindrical surface. Adjust the left edge of this indication to line 10 on the screen with the range control.

M-461.2.3 Repeat Adjustments. Repeat delay and range control adjustments until the 1 in. (25 mm) and 2 in. (50 mm) indications start at sweep lines 5 and 10.

M-461.2.4 Sweep Readings. The sweep now represents 2 in. (50 mm) of sound path distance.

M-461.3 Straight Beam Search Unit and Reference Blocks (See Fig. M-461.3)

NOTE: This technique provides sweep calibration for metal path.

M-461.3.1 Search Unit Placement. Position a straight beam search unit on a 1 in. (25 mm) thick reference block so as to display multiple back-wall indications.

M-461.3.2 Delay Control Adjustment. Adjust the left edge of the first back-wall indication to line 5 on the screen with the delay control.

M-461.3.3 Range Control Adjustment. Adjust the left edge of the second back-wall indication to line 10 on the screen with the range control.

M-461.3.4 Repeat Adjustments. Repeat delay and range control adjustments until the 1 in. (25 mm) and 2 in. (50 mm) indications start at sweep lines 5 and 10.

M-461.3.5 Final Delay Adjustment. Remove the straight beam search unit from the coaxial cable and connect the angle beam search unit to the system. Position the search unit for the maximum indication from the 2 in. (50 mm) cylindrical surface. Adjust the left edge of this indication to line 10 on the screen with the delay control.

M-461.3.6 Sweep Readings. The sweep now represents 2 in. (50 mm) of sound path distance.

M-462 Distance Amplitude Correction (DAC) (See Fig. M-462)

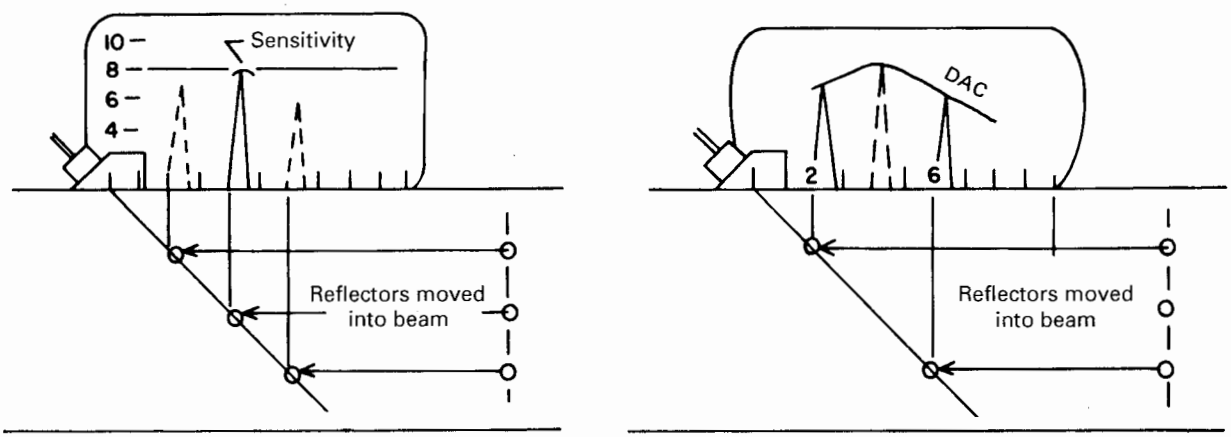
(a) Position the search unit for maximum response from the SDH that gives the highest amplitude.

(b) Adjust the sensitivity (gain) control to provide an indication of 80% (±5%) of full screen height. This is the primary reference level. Mark the peak of this indication on the screen.

(c) Position the search unit for maximum response from another SDH and mark the peak of the indication on the screen.

(d) Position the search unit for maximum response from the third SDH and mark the peak on the screen.

(e) Connect the screen marks of the SDHs to provide the DAC curve.



(a) Sensitivity

(b) Distance Amplitude

FIG. M-462 SENSITIVITY AND DISTANCE-AMPLITUDE CORRECTION

A06

APPENDIX N — TIME OF FLIGHT DIFFRACTION (TOFD) INTERPRETATION

N-410 SCOPE

This Appendix is to be used as an aid for the interpretation of Time of Flight Diffraction (TOFD) ultrasonic images. Diffraction is a common ultrasonic phenomenon and occurs under much broader conditions than just longitudinal-longitudinal diffraction as used in typical TOFD examinations. This interpretation guide is primarily aimed at longitudinal-longitudinal diffraction TOFD setups using separated transducers on either side of the weld on a plate, pipe, or curved vessel. Other possibilities include:

(a) shear-shear diffraction

(b) longitudinal-shear diffraction

(c) single transducer diffraction (called "back diffraction" or the "tip-echo method"

(c) twin transducer TOFD with both transducers on the same side of the flaw/weld

(d) complex inspections, e.g., nozzles

N-420 GENERAL

N-421 TOFD Images — Data Visualization

(a) TOFD data is routinely displayed as a grayscale image of the digitized A-scan. Figure N-421(a) shows the grayscale derivation of an A-scan (or waveform) signal.

(b) TOFD images are generated by the stacking of these grayscale transformed A-scans as shown in Fig. N-421(b). The lateral wave and backwall signals are visible as continuous multicycle lines. The midwall flaw shown consists of a visible upper and lower tip signal. These show as intermediate multicycle signals between the lateral wave and the backwall.

(c) TOFD grayscale images display phase changes, some signals are white-black-white; others are black-white-black. This permits identification of the wave source (flaw top or bottom, etc.), as well as being used for flaw sizing. Depending on the phase of the incident pulse (usually a negative voltage), the lateral wave would be positive, then the first diffracted (upper tip) signal negative, the second diffracted (lower tip) signal positive, and the backwall signal negative. This is shown schematically in Fig. N-421(c). This phase information is very useful for signal interpretation; consequently, RF signals and unrectified signals are used for TOFD. The phase information is used for correctly identifying signals (usually the top and bottom of flaws, if they can be differentiated), and for determining the correct location for depth measurements.

(d) An actual TOFD image is shown in Fig. N-421(d), with flaws. The time-base is horizontal and the axis of motion is vertical [the same as the schematic in Fig. N-421(c)]. The lateral wave is the fairly strong multicycle pulse at left, and the backwall the strong multicycle pulse at right. The flaws show as multicycle gray and white reflections between the lateral and backwall signals. The scan shows several separate flaws (incomplete fusion, porosity, and slag). The ultrasonic noise usually comes from grain reflections, which limits the practical frequency that can be used. TOFD scans may only show the lateral wave (OD) and backwall (ID), with "noise." There is also ultrasonic information available past the backwall (typically shear wave diffractions), but this is generally not used.

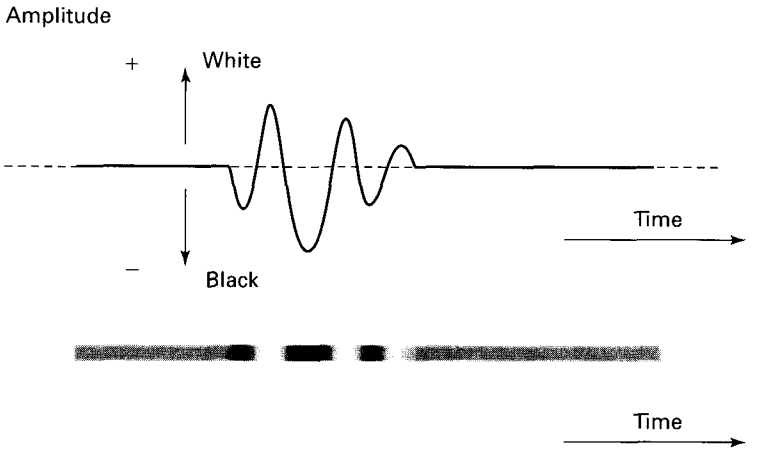


FIG. N-421(a) SCHEMATIC SHOWING WAVEFORM TRANSFORMATION INTO GRAYSCALE

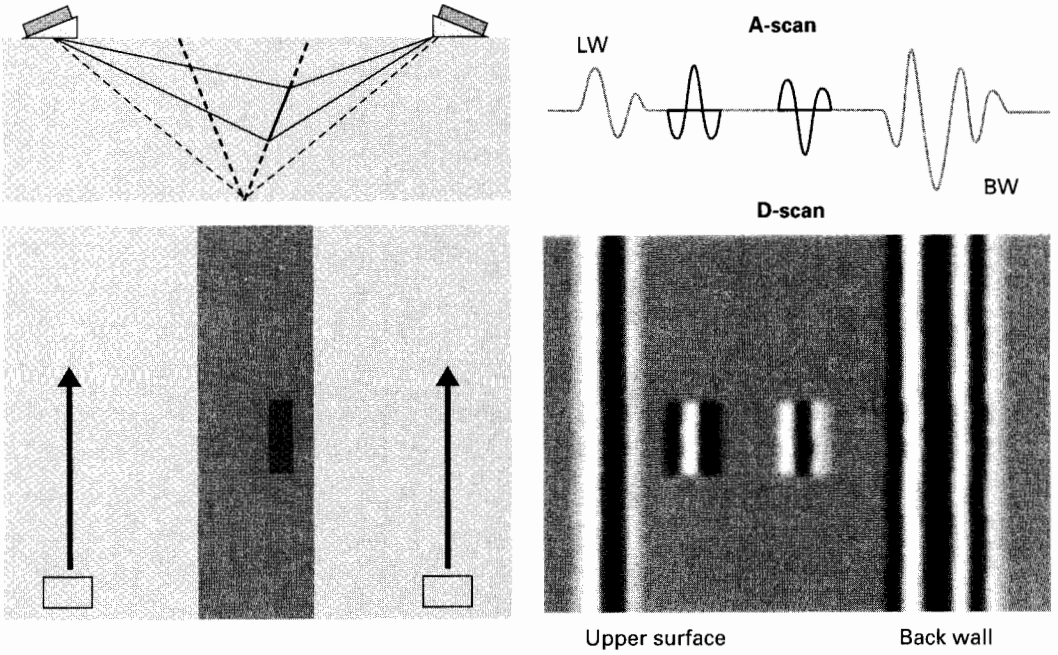


FIG. N-421(b) SCHEMATIC SHOWING GENERATION OF GRAYSCALE B-SCAN FROM MULTIPLE A-SCANS

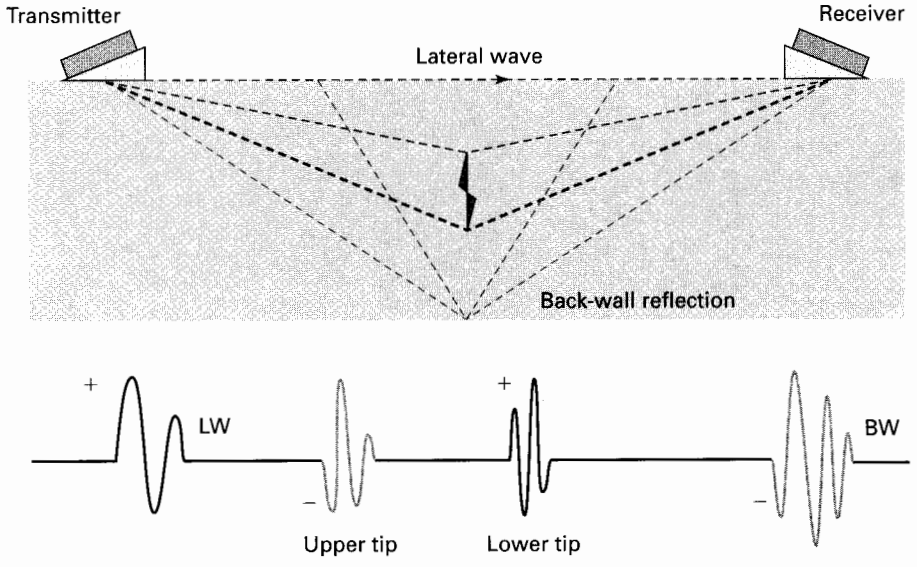


FIG. N-421(c) SCHEMATIC SHOWING STANDARD TOFD SETUP AND DISPLAY WITH WAVEFORM AND SIGNAL PHASES

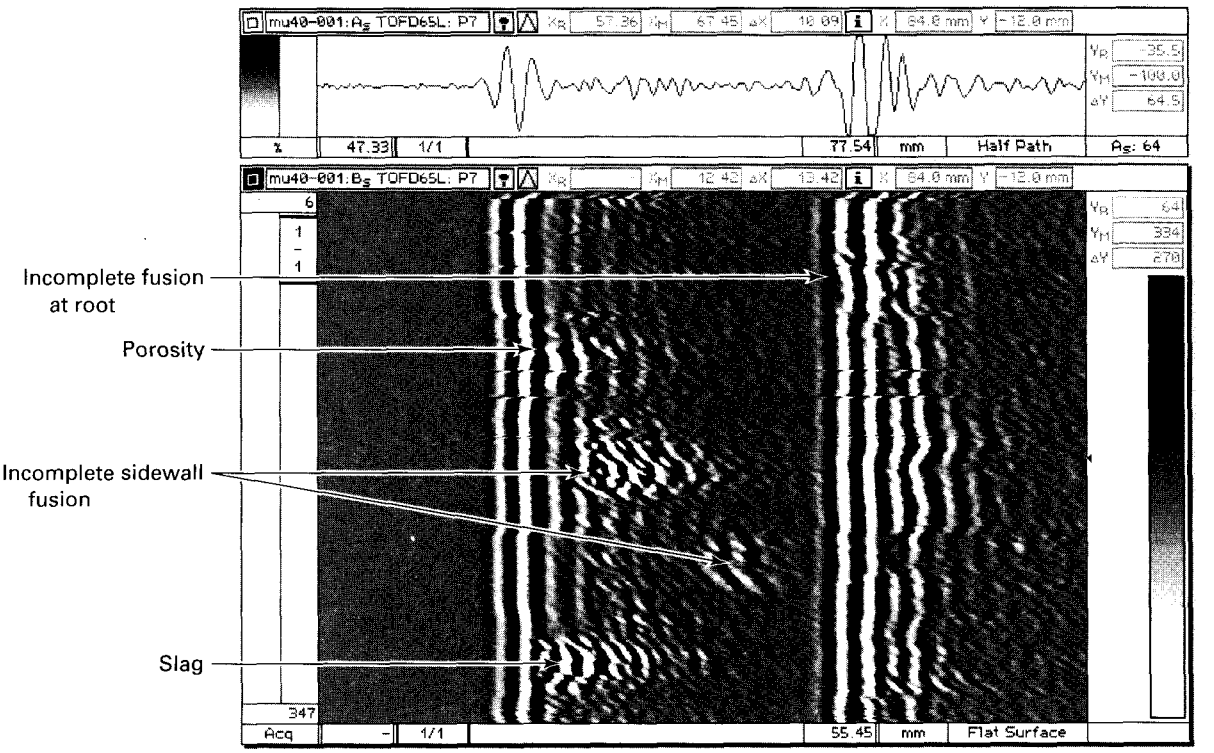


FIG. N-421(d) TOFD DISPLAY WITH FLAWS AND DISPLAYED A-SCAN. TIME IS HORIZONTAL AND THE AXIS OF MOTION IS VERTICAL

N-450 PROCEDURE

N-451 Measurement Tools

TOFD variables are probe spacing, material thickness, sound velocity, transducer delay, and lateral wave transit and backwall reflection arrival time. Not all the variables need to be known for flaw sizing. For example, calibration using just the lateral wave (front wall or OD) and backwall (ID) signals can be performed without knowing the transducers delay, separation, or velocity. The arrival time, Fig. N-451, of the lateral wave (t_1) and the backwall signal (t_2) are entered into the computer software and cursors are then displayed for automated sizing.

N-452 Flaw Position Errors

Flaws will not always be symmetrically placed between the transmitter and receiver transducers. Normally, a single pair of transducers is used, centered on the weld axis. However, multiple TOFD sets can be used, particularly on heavy wall vessels, and offsets are used to give improved detection. Also, flaws do not normally occur on the weld centerline. Either way, the flaws will not be positioned symmetrically, Fig. N-452(a) and this will be a source or error in location and sizing.

There will be positional and sizing errors associated with a noncentered flaw, as shown in Fig. N-452(b). However, these errors will be small, and generally are tolerable since the maximum error due to off-axis position is less than 10% and the error is actually smaller yet since both the top and bottom of the flaw are offset by similar amounts. The biggest sizing problems occur with small flaws near the backwall. Exact error values will depend on the inspection parameters.

N-453 Measuring Flaw Length

Flaw lengths parallel to the surface can be measured from the TOFD image by fitting hyperbolic cursors to the ends of the flaws (see Fig. N-453).

N-454 Measuring Flaw Depth

Flaw height perpendicular to the surface can be measured from the TOFD image by fitting cursors on the top and bottom tip signals. The following are two examples of depth measurements of weld flaws in a 1 in. (25 mm) thick plate. Figure N-454(a) is midwall lack of fusion and Fig. N-454(b) is a centerline crack. Note that TOFD signals are not linear, so midwall flaws show in the upper

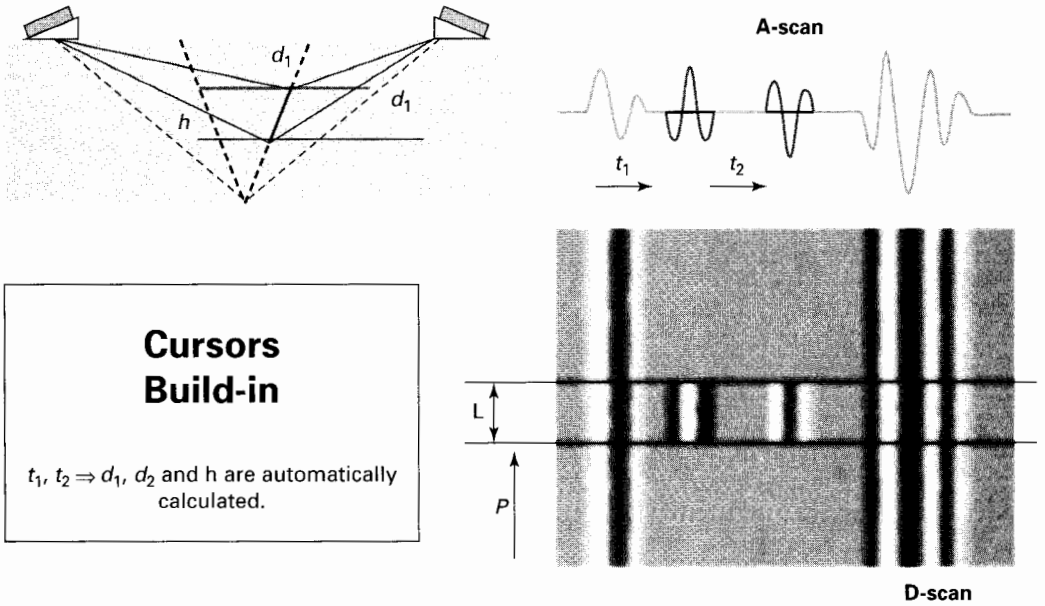


FIG. N-451 MEASUREMENT TOOLS FOR FLAW HEIGHTS

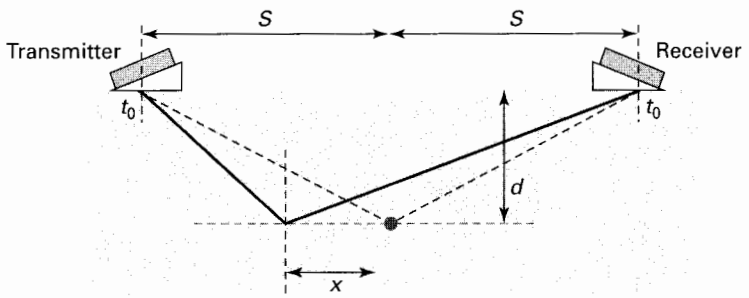
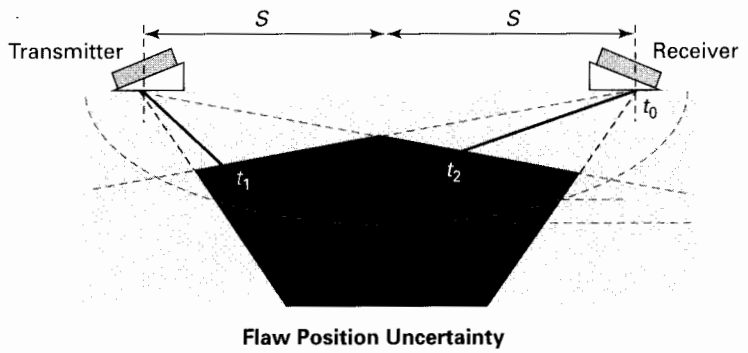


FIG. N-452(a) SCHEMATIC SHOWING THE DETECTION OF OFF-AXIS FLAWS



GENERAL NOTE: In practice, the maximum error on absolute depth position lies below 10%. The error on height estimation of internal (small) flaws is negligible. Be careful of small flaws situated at the backwall.

FIG. N-452(b) MEASUREMENT ERRORS FROM FLAW POSITION UNCERTAINTY

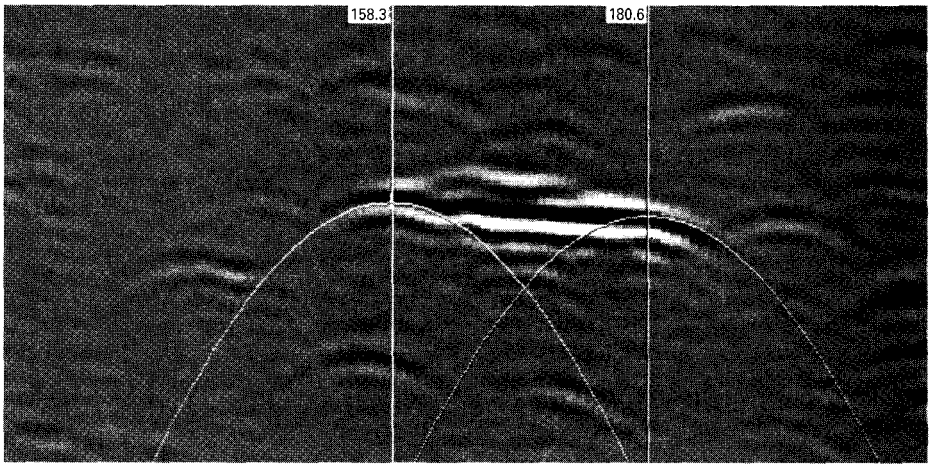


FIG. N-453 TOFD IMAGE SHOWING HYPERBOLIC "TAILS" FROM THE ENDS OF A FLAW IMAGE USED TO MEASURE FLAW LENGTH

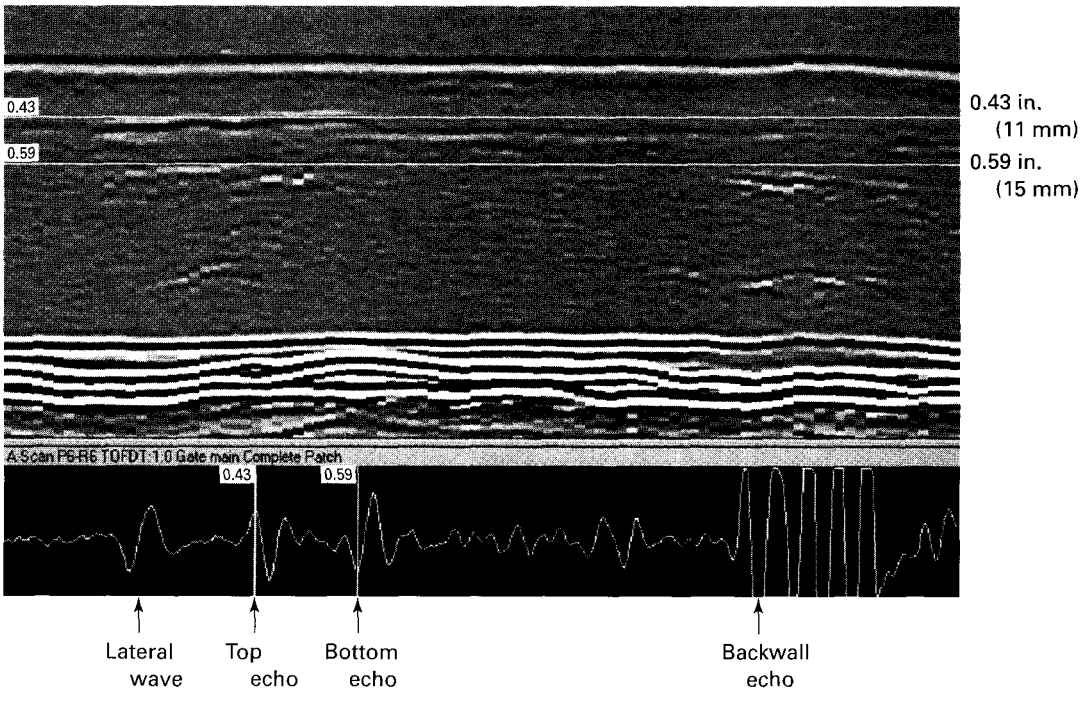


FIG. N-454(a) TOFD IMAGE SHOWING TOP AND BOTTOM DIFFRACTED SIGNALS FROM MIDWALL FLAW AND A-SCAN INTERPRETATION

third region of the image. It is possible to linearize the TOFD scans by computer software.

N-480 EVALUATION

This section shows a variety of TOFD images and the interpretation/explanation. Unfortunately, there are significant variations amongst flaws and TOFD setups and displays, so the following images should be used as a guide only. Evaluator experience and analysis skills are very important as well.

N-481 Single Flaw Images

(a) Point flaws [Fig. N-481(a)], like porosity, show up as single multicycle points between the lateral and backwall signals. Point flaws typically display a single

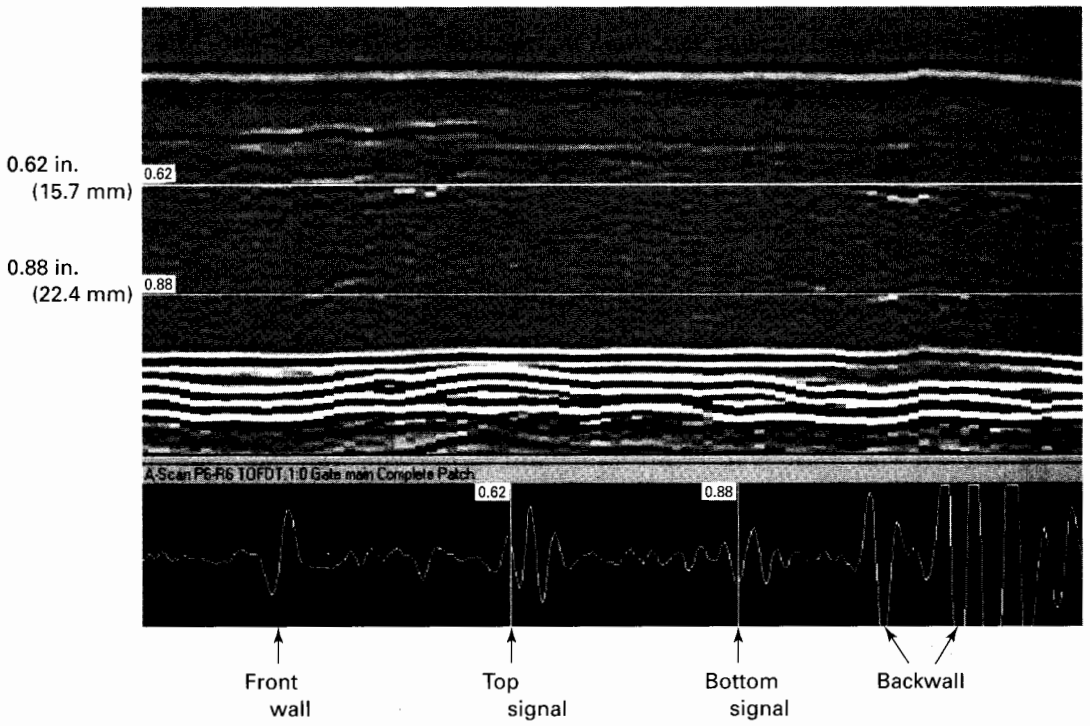


FIG. N-454(b) TOFD IMAGE SHOWING TOP AND BOTTOM DIFFRACTED SIGNALS FROM CENTERLINE CRACK AND A-SCAN INTERPRETATION

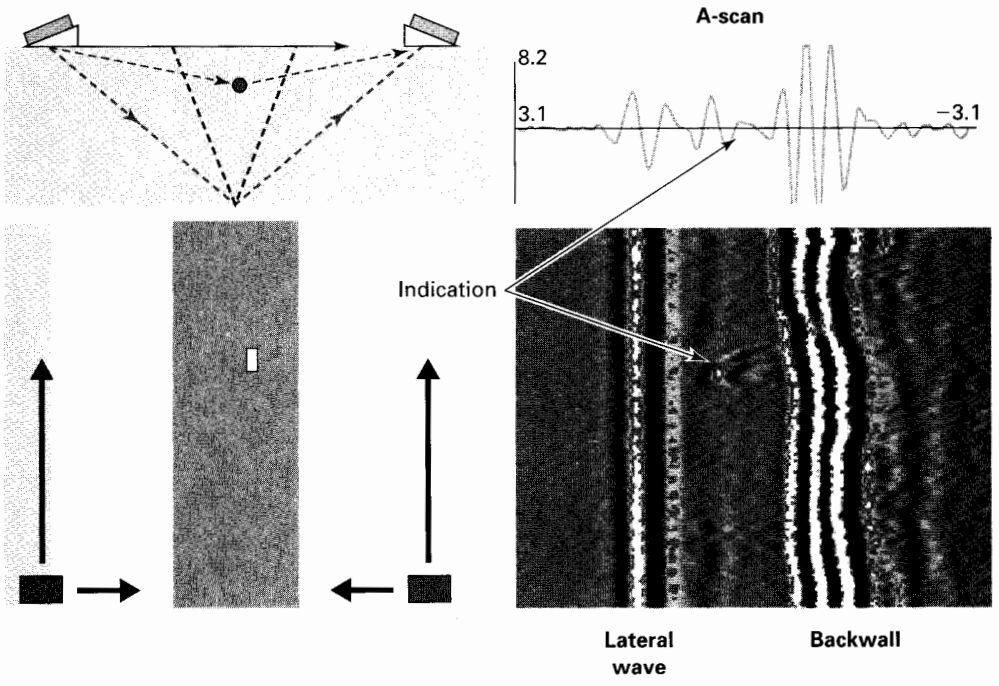


FIG. N-481(a) SCHEMATICS OF IMAGE GENERATION, SCAN PATTERN, WAVEFORM, AND TOFD DISPLAY SHOWING THE IMAGE OF THE POINT FLAW

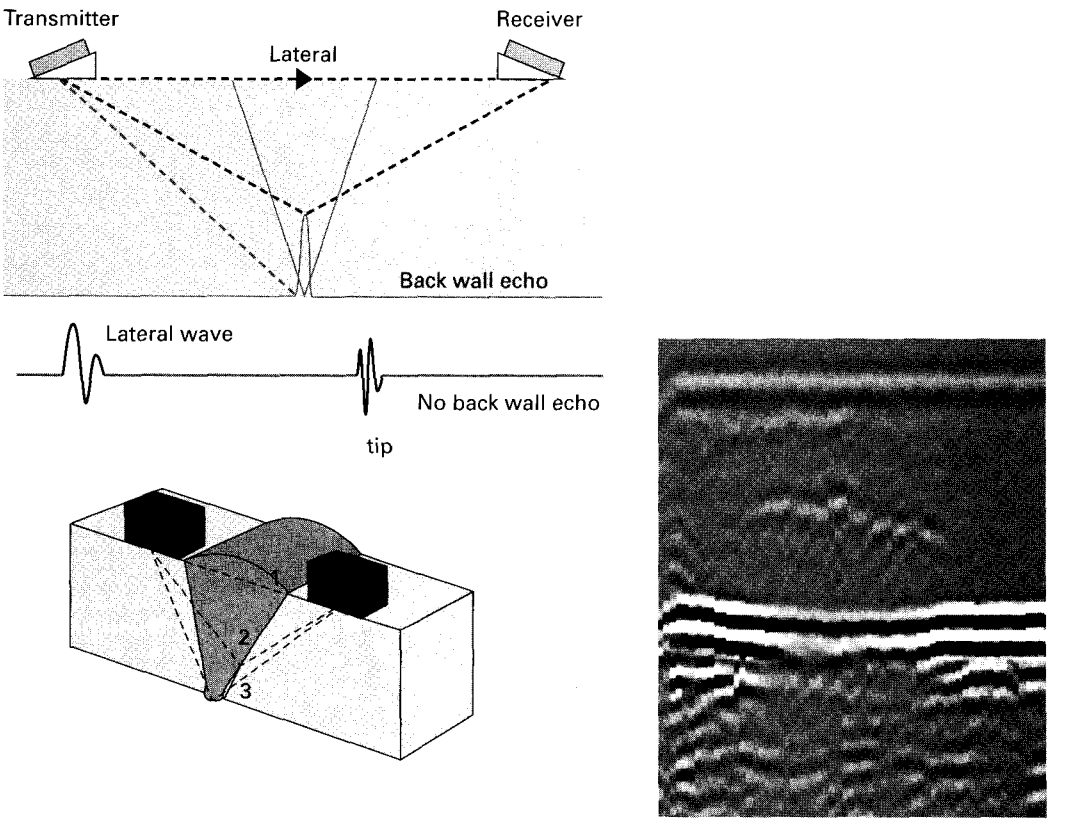


FIG. N-481(b) SCHEMATICS OF IMAGE GENERATION, FLAW LOCATION, AND TOFD DISPLAY SHOWING THE IMAGE OF THE INSIDE (ID) SURFACE-BREAKING FLAW

TOFD signal since flaw heights are smaller than the ring-down of the pulse (usually a few millimeters, depending on the transducer frequency and damping). Point flaws usually show parabolic "tails" where the signal drops off towards the backwall.

(b) Inside (ID) far-surface-breaking flaws [Fig. N-481(b)] shows no interruption of the lateral wave, a signal near the backwall, and a related interruption or break of the backwall (depending on flaw size).

(c) Near-surface-breaking flaws [Fig. N-481(c)] shows perturbations in the lateral wave. The flaw breaks the lateral wave, so TOFD can be used to determine if the flaw is surface-breaking or not. The lower signal can then be used to measure the depth of the flaw. If the flaw is not surface-breaking, i.e., just subsurface, the lateral wave will not be broken. If the flaw is near-subsurface and shallow (that is, less than the ringing time of the lateral wave or a few millimeters deep), then the flaw will probably be invisible to TOFD. The image also displays a number of signals from point flaws.

(d) Midwall flaws [Fig. N-481(d)] show complete lateral and backwall signals, plus diffraction signals from the top and bottom of the flaw. The flaw tip echoes provide a very good profile of the actual flaw. Flaw sizes can be readily black-white, while the lower echo is black-white-black. Also note the hyperbolic curve that is easily visible at the left end of the top echo; this is similar to the effect from a point flaw [see N-481(a)] and permits accurate length measurement of flaws [see N-450(a)].

If a midwall flaw is shallow, i.e., less than the transducer pulse ring-down (a few millimeters), the top and bottom tip signals cannot be separated. Under these circumstances, it is not possible to differentiate the top from the bottom of the flaw, so the evaluator can only say that the flaw is less than the ringdown distance (which depends on transducer frequency and damping, etc.).

(e) Lack of root penetration [see Fig. N-481(e)] is similar to an inside (ID) far-surface-breaking flaw [see N-481(b)]. This flaw gives a strong diffracted signal (or more correctly, a reflected signal) with a phase inversion from the backwall signal. Note that whether signals are diffracted or reflected is not important for TOFD characterization; the analysis and sizing is the same. Also note even though there is a perturbation of the backwall signal, the backwall is still visible across the whole flaw. This material also shows small point flaws and some grain

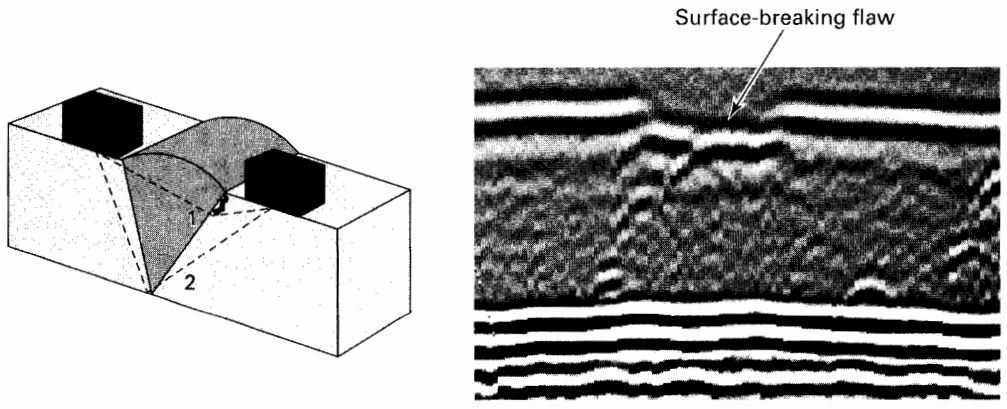


FIG. N-481(c) SCHEMATICS OF IMAGE GENERATION, FLAW LOCATION, AND TOFD DISPLAY SHOWING THE IMAGE OF THE OUTSIDE (OD) SURFACE-BREAKING FLAW

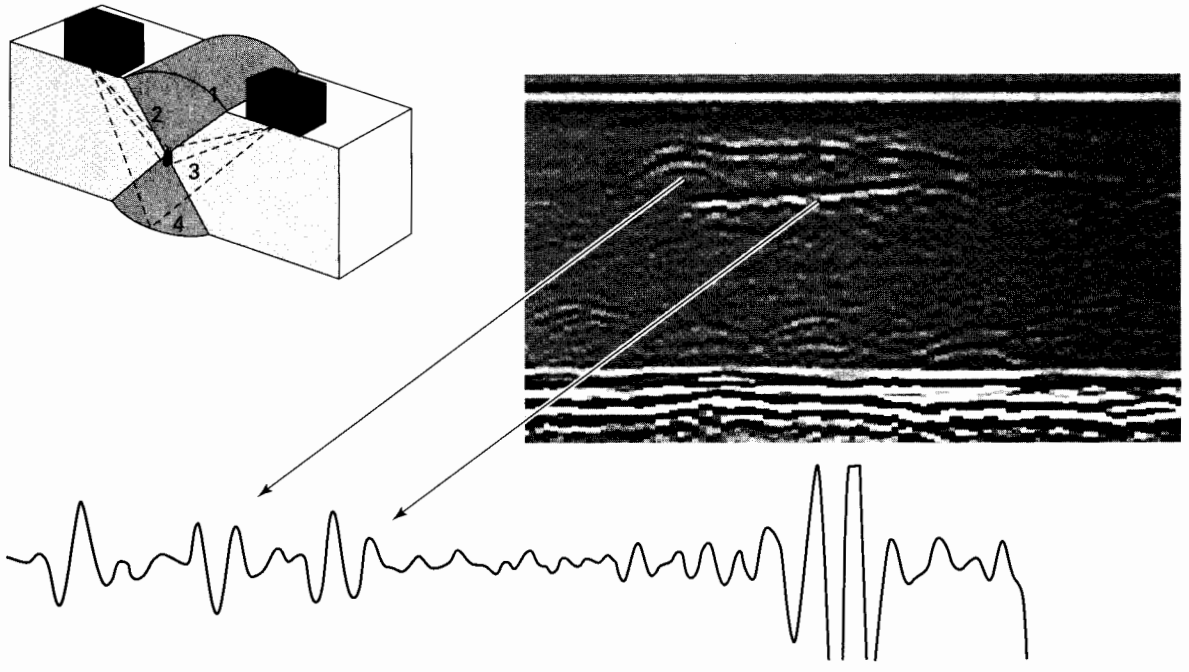


FIG. N-481(d) SCHEMATICS OF FLAW LOCATION, SIGNALS, AND TOFD DISPLAY SHOWING THE IMAGE OF THE MIDWALL FLAW

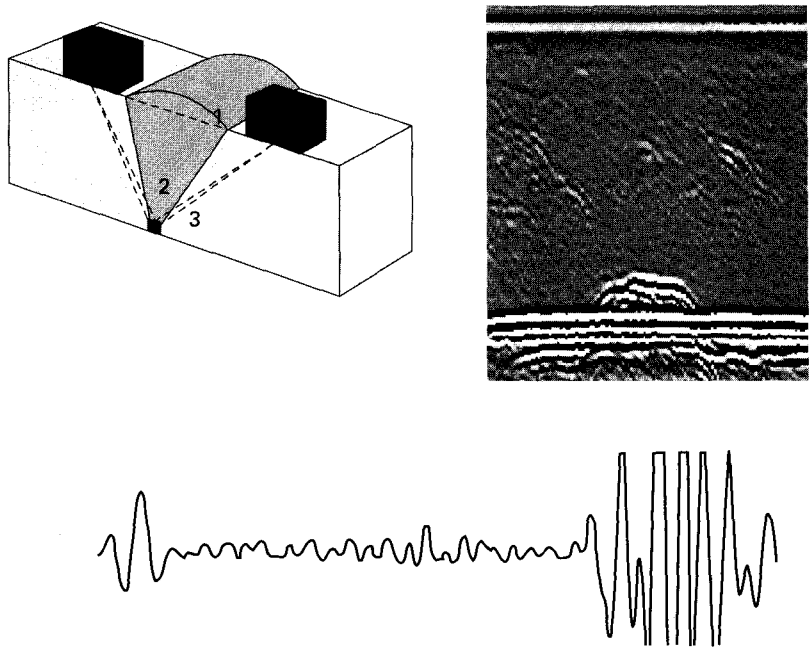


FIG. N-481(e) FLAW LOCATION AND TOFD DISPLAY SHOWING THE IMAGE OF THE LACK OF ROOT PENETRATION

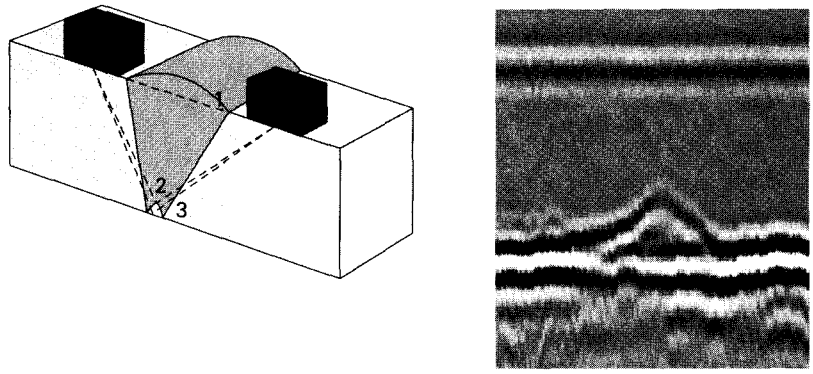


FIG. N-481(f) FLAW LOCATION AND TOFD DISPLAY SHOWING THE IMAGE OF THE CONCAVE ROOT FLAW

noise, which is quite common. TOFD typically overemphasizes small point flaws, which are normally undetected by conventional shear wave pulse-echo techniques.

(f) Concave root flaws [see Fig. N-481(f)] are similar to lack of root penetration. The top of the flaw is visible in the TOFD image, as well as the general shape. The backwall signal shows some perturbation as expected.

(g) Sidewall lack of fusion [see Fig. N-481(g)] is similar to a midwall flaw [see N-481(d)] with two differences. First, the flaw is angled along the fusion line, so TOFD is effectively independent of orientation, which is not a problem for TOFD. Second, the upper flaw signal is partly buried in the lateral wave for this particular flaw. In this instance, the upper tip signal is detectable since the lateral wave signal amplitude is noticeably increased. However, if this were not the case, then the evaluator would be unable to accurately measure the flaw depth.

(h) Porosity [see Fig. N-481(h)] appears as a series of hyperbolic curves of varying amplitudes, similar to the point flaw [see N-481(a)]. The TOFD hyperbolic curves are superimposed since the individual porosity pores are closely spaced. This does not permit accurate analysis, but the unique nature of the image permits characterization of the signals as "multiple small point flaws," i.e., porosity.

(i) Transverse cracks [see Fig. N-481(i)] are similar to a point flaw [see N-481(a)]. The TOFD scan displays

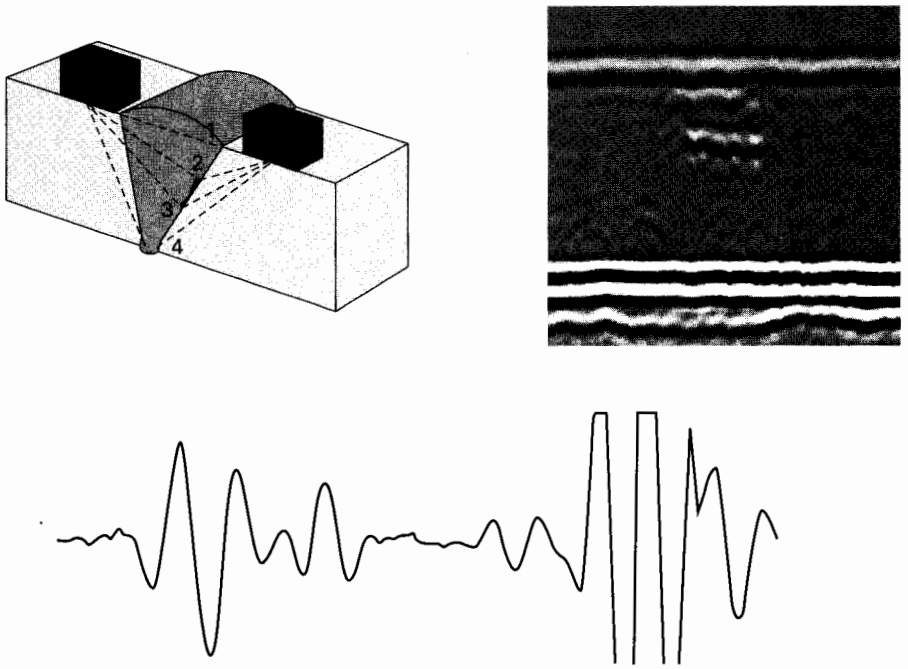


FIG. N-481(g) FLAW LOCATION, TOFD DISPLAY SHOWING THE IMAGE OF THE MIDWALL LACK OF FUSION FLAW, AND THE A-SCAN

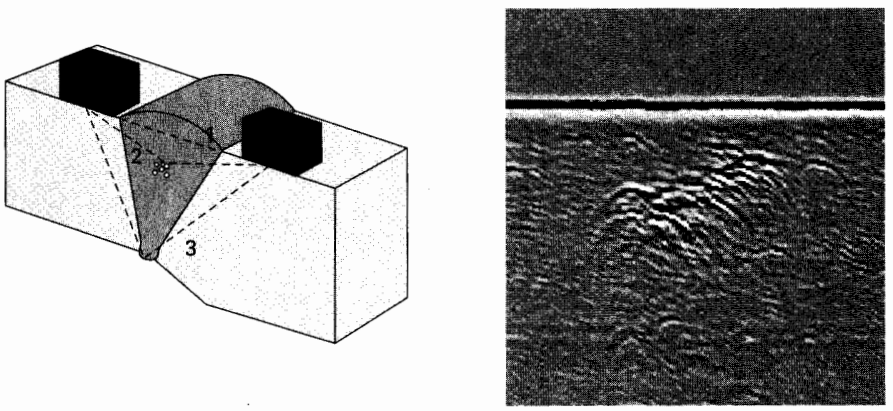


FIG. N-481(h) FLAW LOCATION AND TOFD DISPLAY SHOWING THE IMAGE OF THE POROSITY

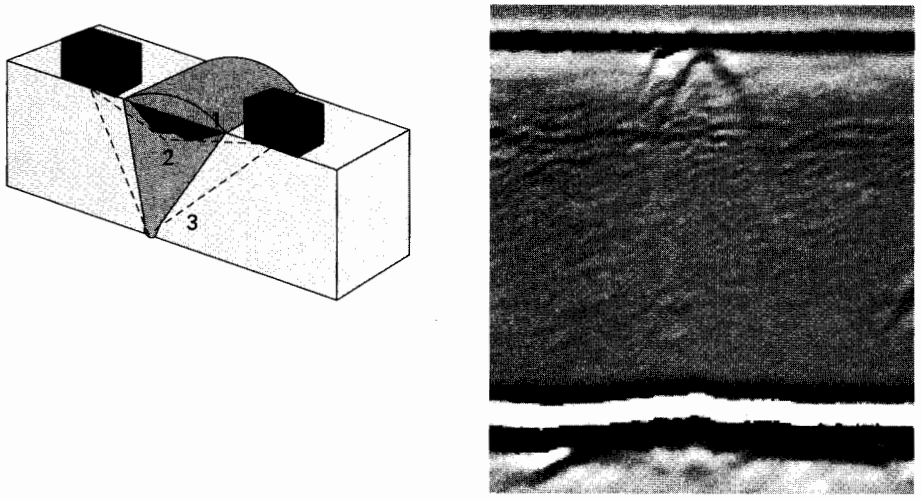
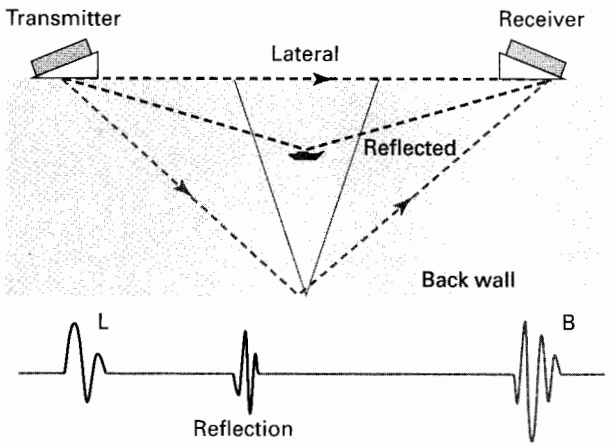
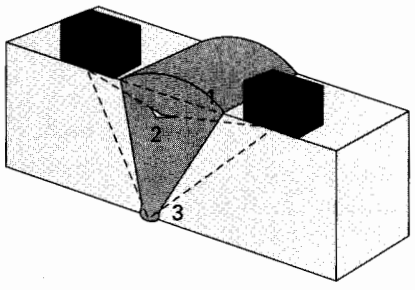


FIG. N-481(i) FLAW LOCATION AND TOFD DISPLAY SHOWING THE IMAGE OF THE TRANSVERSE CRACK





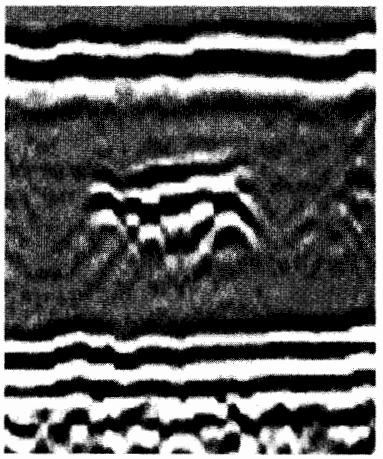


FIG. N-481(j) SCHEMATICS OF IMAGE GENERATION, FLAW LOCATION AND TOFD DISPLAY SHOWING THE IMAGE OF THE INTERPASS LACK OF FUSION

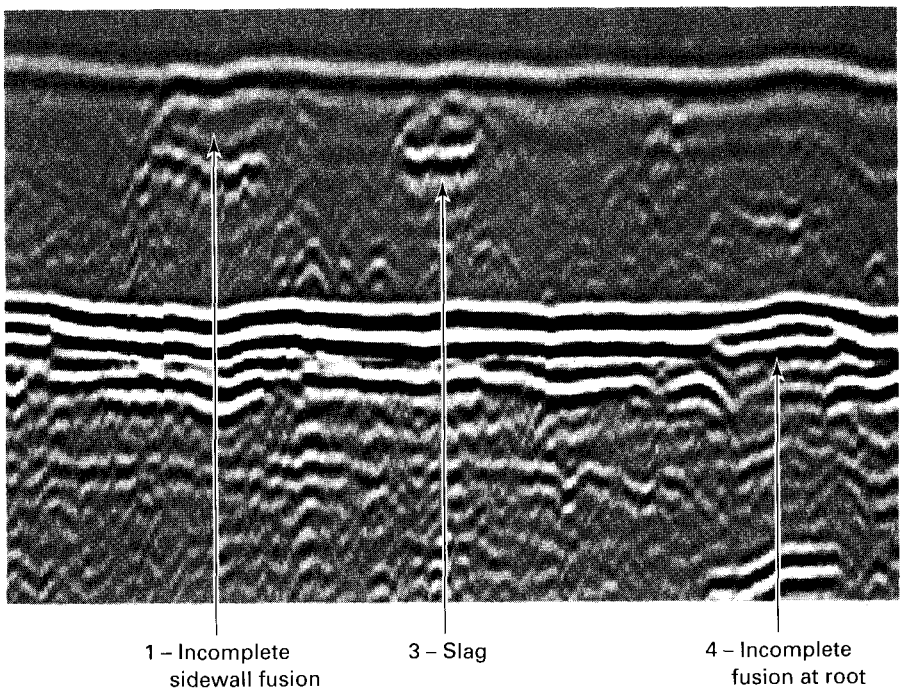


FIG. N-482(a) SCHEMATIC OF FLAW LOCATIONS AND TOFD IMAGE SHOWING THE LATERAL WAVE, BACKWALL, AND THREE OF THE FOUR FLAWS

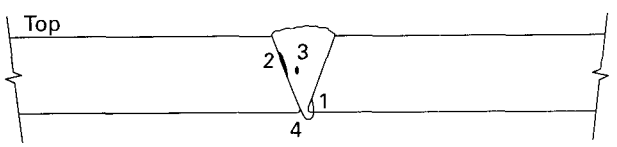
a typical hyperbola. Normally, it would not be possible to differentiate transverse cracks from near-surface porosity using TOFD; further inspection would be needed.

(j) Interpass lack of fusion [see Fig. N-481(j)] shows as a single, high amplitude signal in the midwall region. If the signal is long, it is easily differentiated from porosity or point sources. It is not possible to distinguish the top and bottom, as these do not exist as such. Note the expected phase change from the lateral wave. Interpass lack of fusion signals are generally benign.

N-482 Multiple Flaw Images

TOFD images of flawed welds contain four flaws each.

N-482.1 Plate 1 [Fig. N-482(a)]



GENERAL NOTES:

1. Root crack (right): ~ 1.6–2.5 in. (40–64 mm) from one end.
2. Incomplete sidewall fusion (mid-left): ~ 4–5 in. (100–125 mm).
3. Slag: ~ 6.4–7.2 in. (163–183 mm).
4. Incomplete fusion at root (left): ~ 9.3–10.5 in. (237–267 mm).

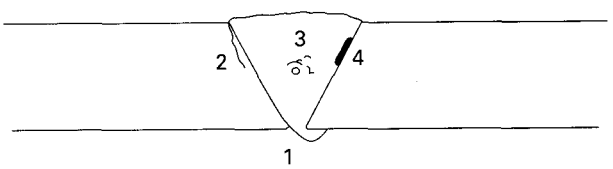
Figure N-482(a) clearly illustrates the significant advantages of TOFD (midwall flaw detection, flaw sizing), the limitations due to dead zones, and that:

(a) the sidewall incomplete fusion shows up clearly, as does the slag

(b) the incomplete fusion at the root was not easily detected, though it did disturb the backwall. This in not surprising in the backwall dead zone due to a shear-shear diffracted wave. This example illustrates the potential value of using information later in the time base, but this is outside the scope of this interpretation manual.

(c) the root crack is not visible at all due to the backwall dead zone

N-482.2 Plate 2 [Fig. N-482(b)]



GENERAL NOTES:

1. Incomplete fusion at root (left): ~ 0.6–.8 in. (15–45 mm) from one end.
2. Toe crack (top left): ~ 3–4 in. (80–100 mm).
3. Porosity: ~ 5.5–6.25 in. (140–160 mm).
4. Incomplete sidewall fusion (upper right): ~ 8–9.25 in. (200–235 mm).

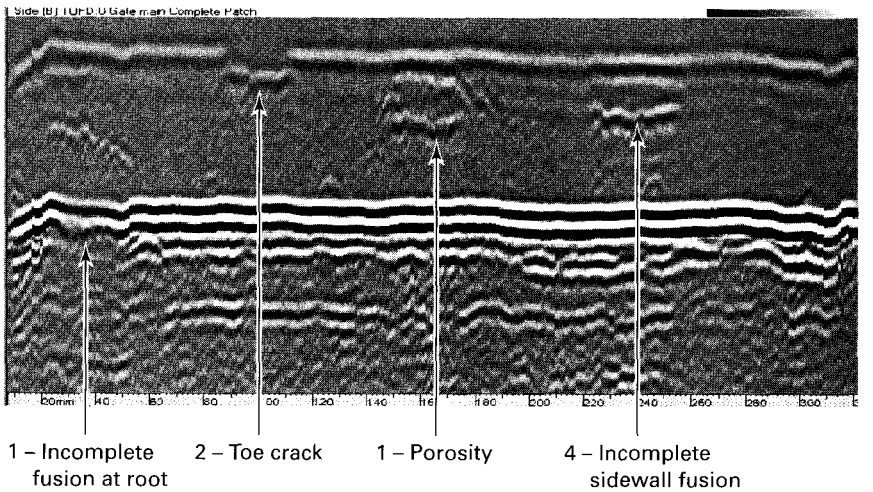


FIG. N-482(b) SCHEMATIC OF FLAW LOCATIONS AND TOFD DISPLAY SHOWING THE LATERAL WAVE, BACKWALL, AND FOUR FLAWS

Figure N-482(b) shows that:

(a) all four flaws are detectable

(b) the incomplete fusion at the root shows up clearly in this scan because it is deeper. Both the backwall perturbation and the flaw tip signals are clear.

(c) the crown toe crack is clearly visible, both by complete disruption of the lateral wave and by the bottom tip signal. Both the incomplete fusion at the root and crown toe crack are identifiable as surface breaking by the disruption of the lateral wave and backwall signal, respectively.

(d) the porosity is visible as a series of signals. This cluster of porosity would be difficult to characterize properly using the TOFD scan alone, since it could be identified as slag or a planar flaw.

(e) the incomplete sidewall fusion is clearly visible and could be easily sized using cursors.

N-483 Typical Problems With TOFD Interpretation

TOFD images can be corrupted by incorrect setups or other problems such as electrical noise. The following images were all made on the same plate to show some of the typical problems that can occur. Starting first with an acceptable scan, and then subsequent scans made to show various corruptions of this image.

(a) Acceptable Scan [Fig. N-483(a)]. The gain and gate setting are reasonable, and the electrical noise is minimal.

(b) Incorrect Low Gain Setting [Fig. N-483(b)]. The lateral wave and some of the diffracted signals are starting to disappear. At yet lower gain levels, some of the diffracted signals would become undetectable.

(c) Incorrect High Gain Setting [Fig. N-483(c)]. The noise level increases to obscure the diffracted signals; this can lead to reduced probability of detection, and poor sizing. High noise levels can also arise from large grains. In this case, the solution is to reduce the ultrasonic frequency.

(d) Correct gate settings are critical, because TOFD A-scans are not that easy to interpret since there are multiple visible signals. As a minimum, the gates should encompass the lateral wave and longitudinal wave backwall signal; the gate can extend to the shear wave backwall, if required. Typically, the best signal to use as a guide is the first (longitudinal wave) backwall, since it is strong and always present (assuming the transducer separation is reasonably correct). The following figures show examples of incorrect gate positioning, which will inherently lead to poor flaw detection.

The first example, Fig. N-483(d)(1), shows the gate set too early, the lateral wave is visible, and the backwall is not. Any inside (ID) near-backwall flaws will be missed.

The second example, Fig. N-483(d)(2), shows the gate set too late. The lateral wave is not visible. The first signal is the backwall, and the second signal is the shear wave backwall. With this setup, all the outside (OD) near-surface flaws will be missed.

The third example, Fig. N-483(d)(3), is with the gate set too long. Though this is not technically incorrect, the image will show the diffracted backwall shear-shear wave

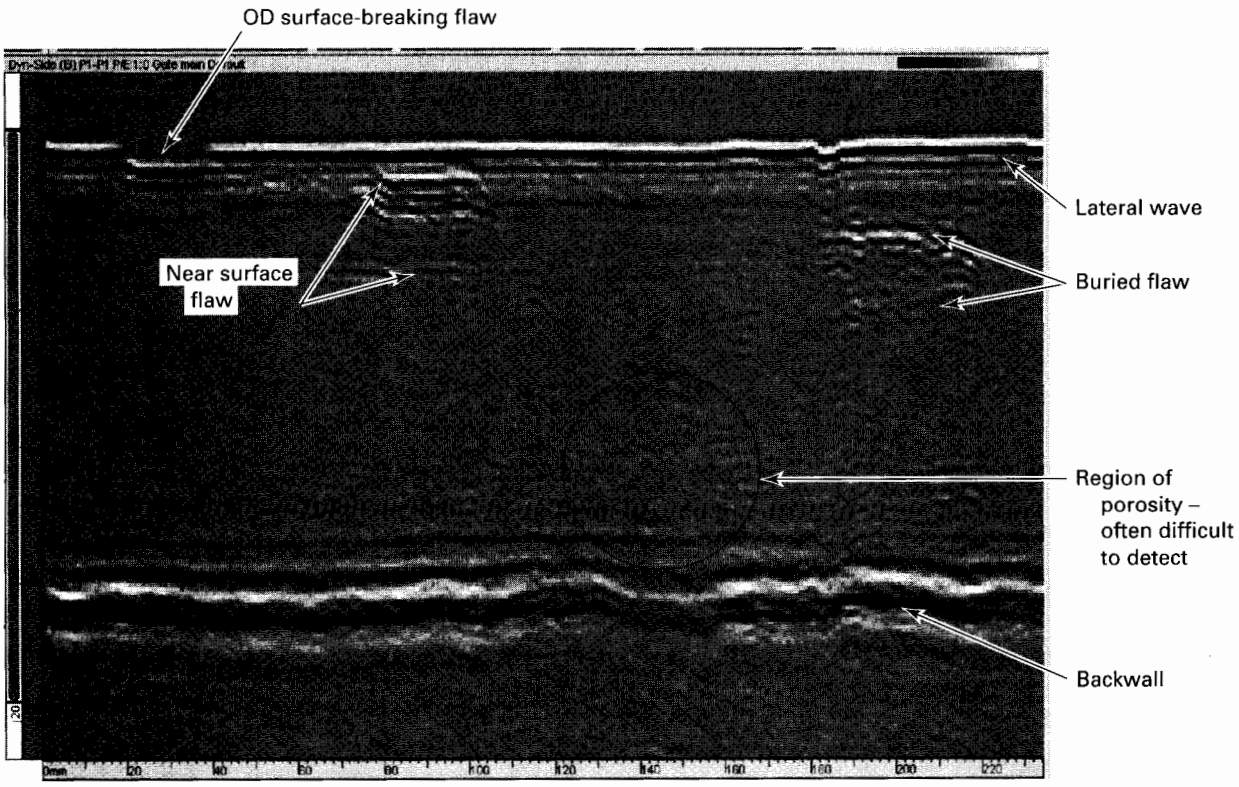


FIG. N-483(a) ACCEPTABLE NOISE LEVELS, FLAWS, LATERAL WAVE, AND LONGITUDINAL WAVE BACKWALL

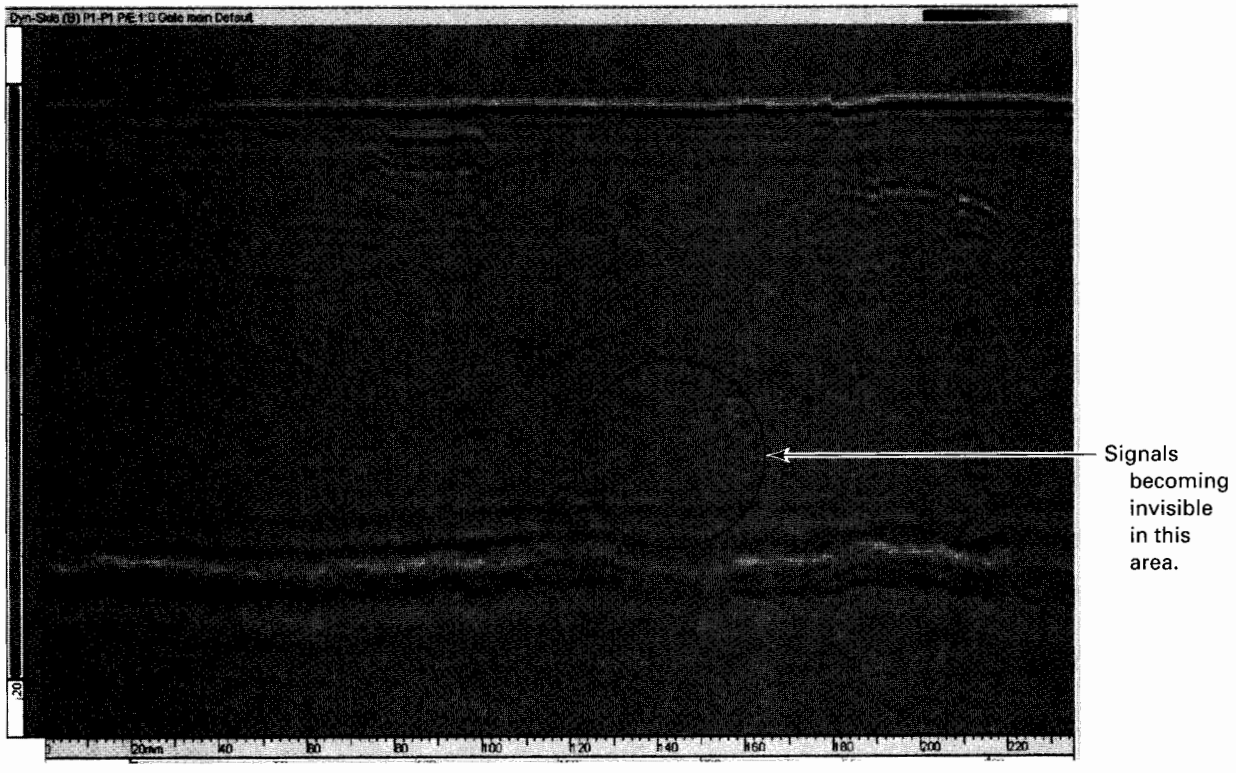


FIG. N-483(b) TOFD IMAGE WITH GAIN TOO LOW

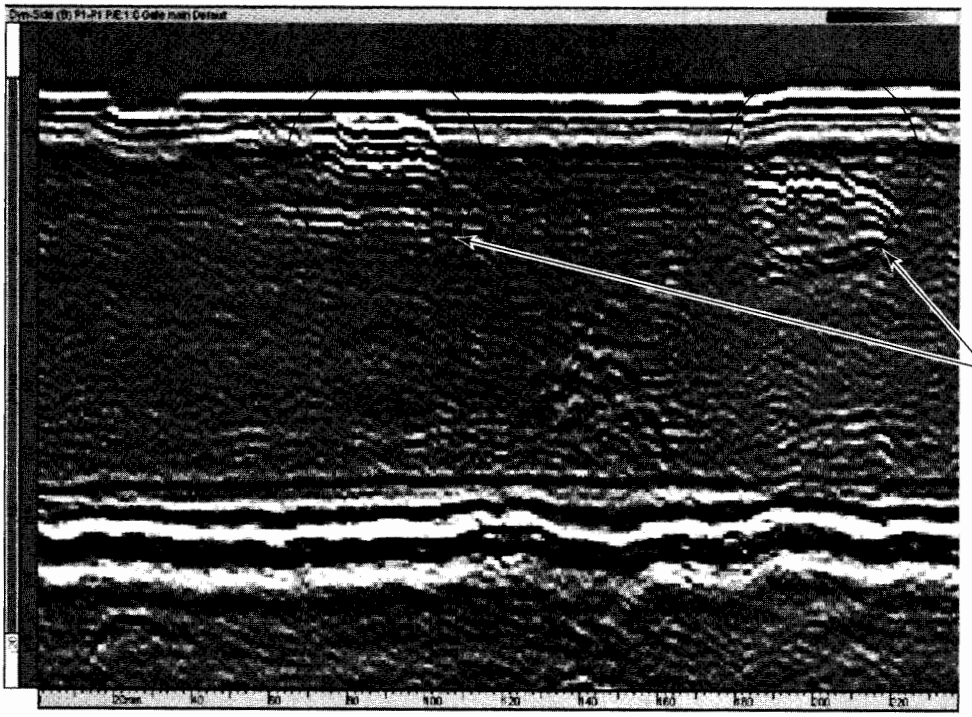


FIG. N-483(c) TOFD IMAGE WITH GAIN SET TOO HIGH

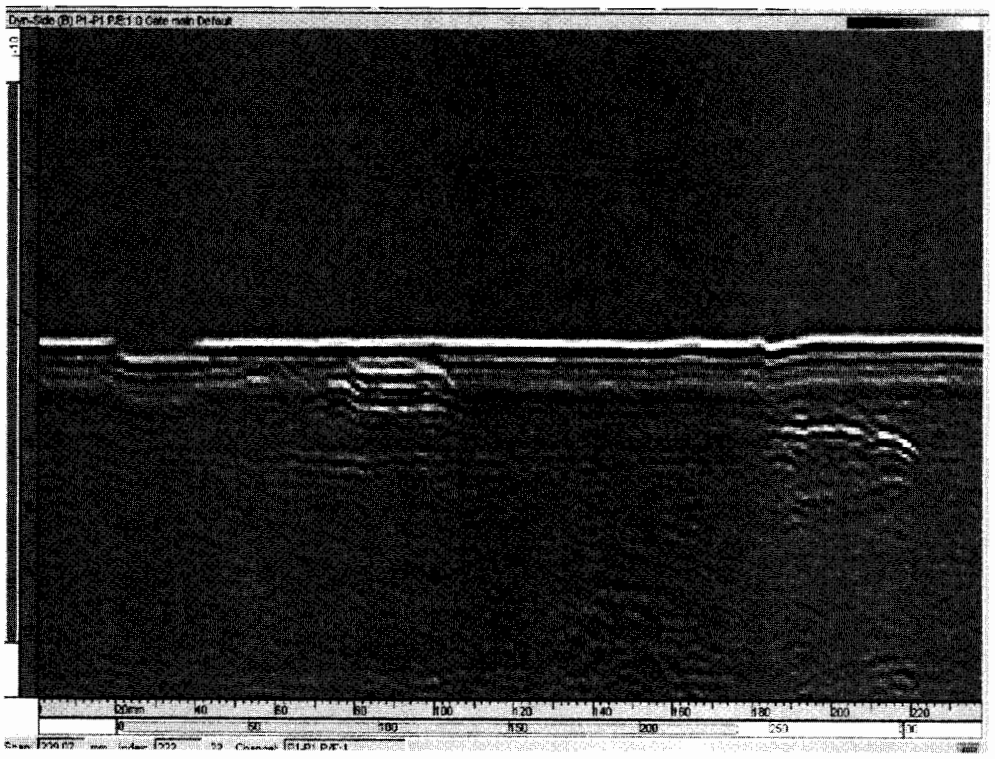


FIG. N-483(d)(1) TOFD IMAGE WITH THE GATE SET TOO EARLY

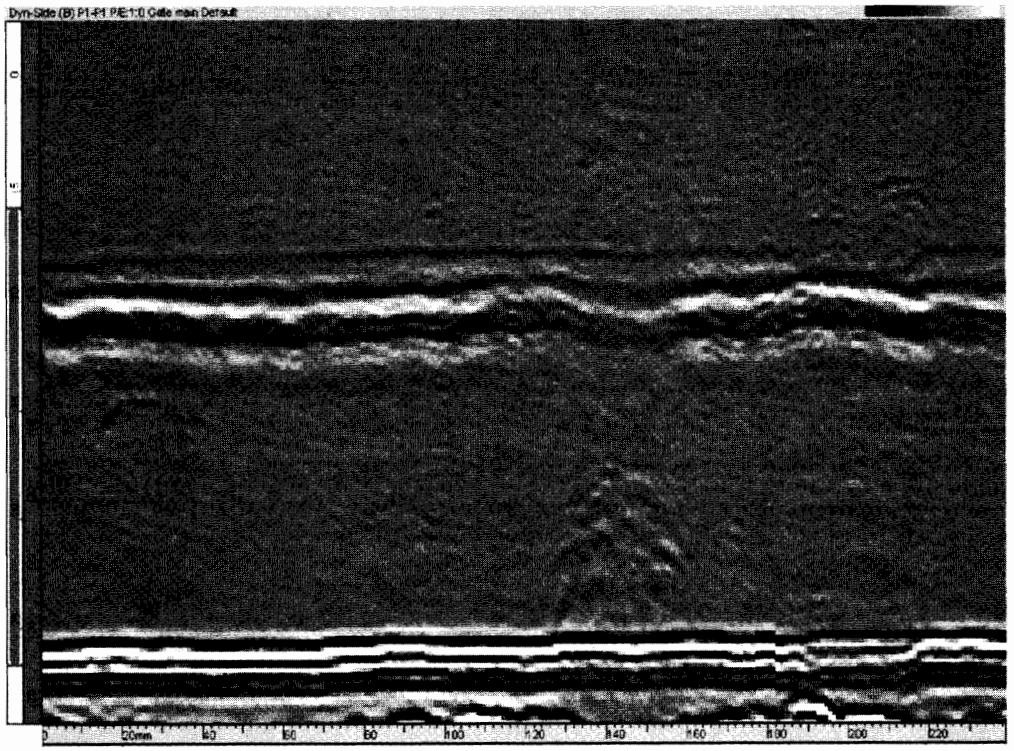


FIG. N-483(d)(2) TOFD IMAGE WITH THE GATE SET TOO LATE

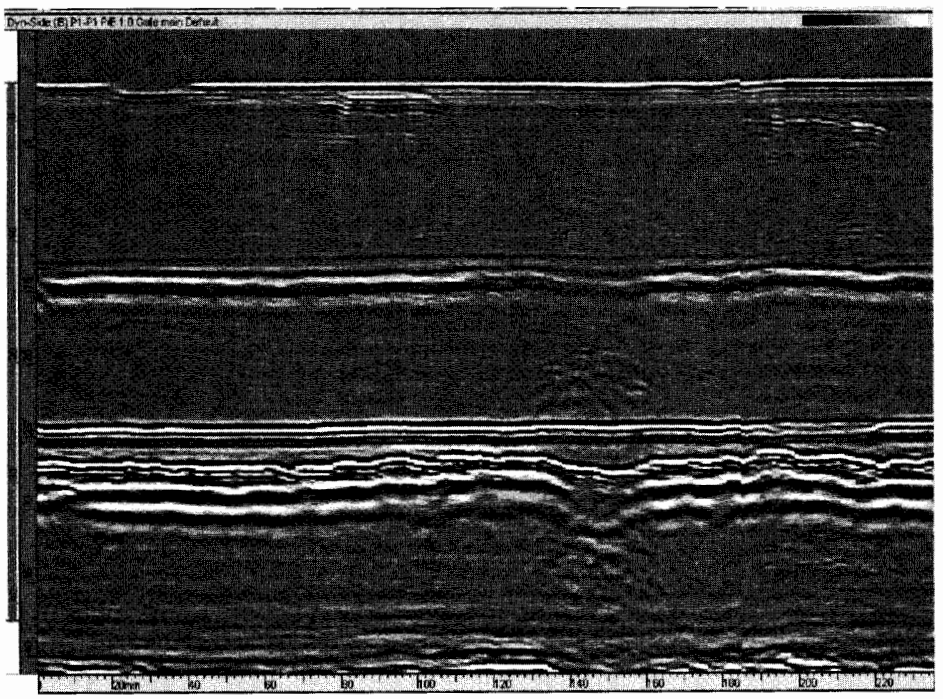


FIG. N-483(d)(3) TOFD IMAGE WITH THE GATE SET TOO LONG

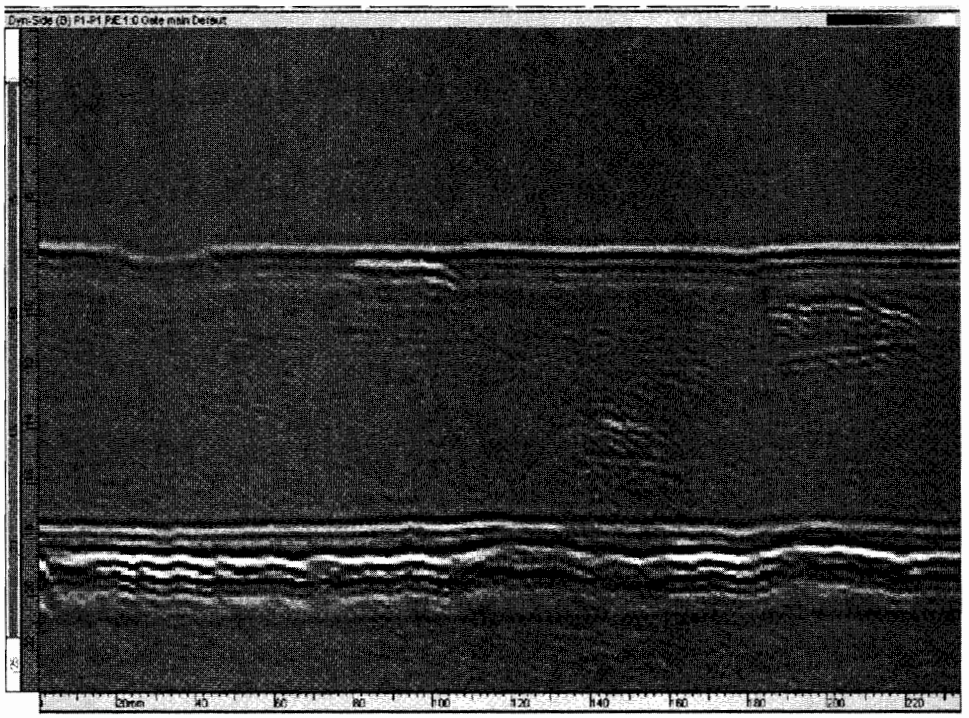


FIG. N-483(e) TOFD IMAGE WITH TRANSDUCERS SET TOO FAR APART

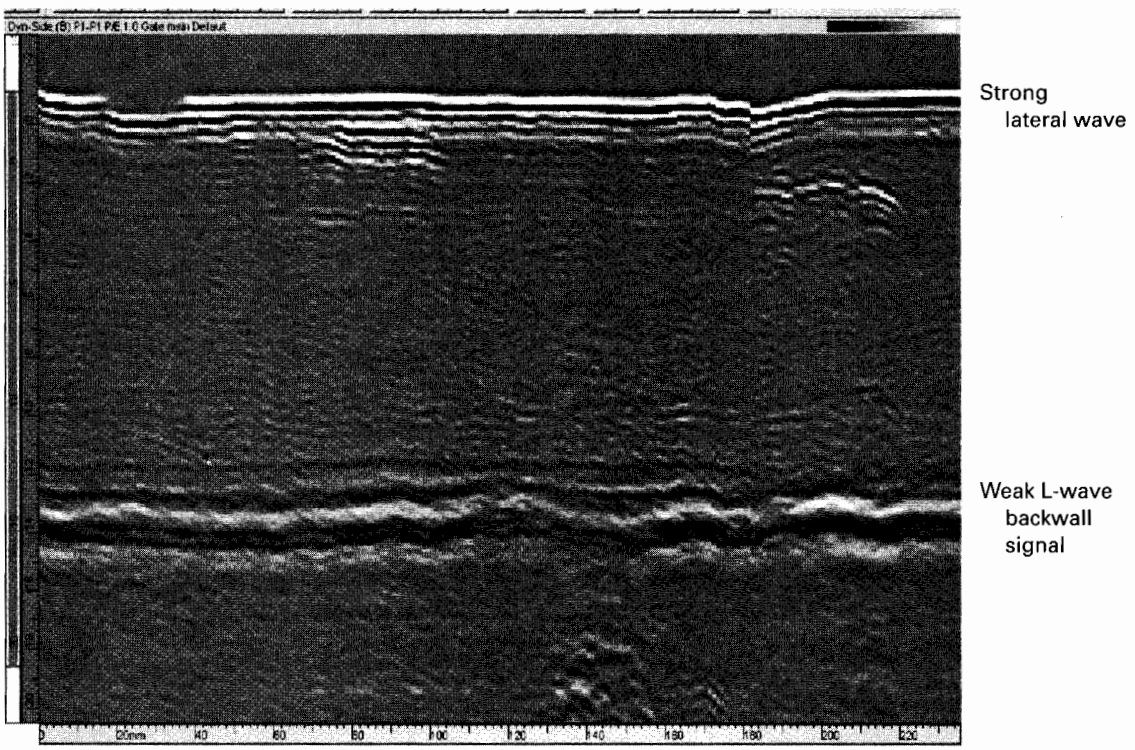


FIG. N-483(f) TOFD IMAGE WITH TRANSDUCERS SET TOO CLOSE TOGETHER

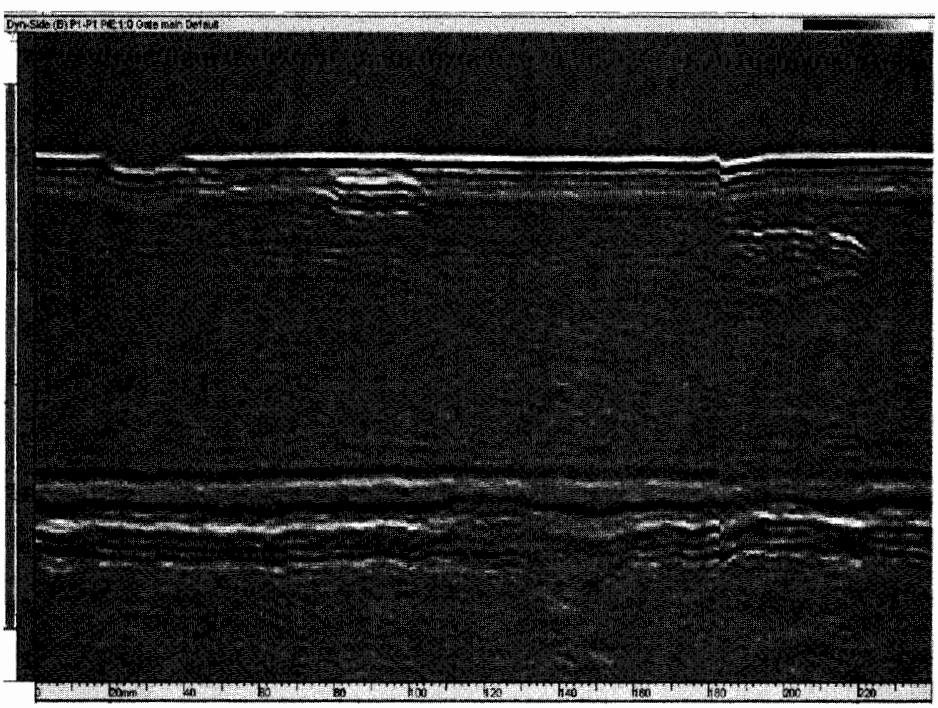


FIG. N-483(g) TOFD IMAGE WITH TRANSDUCERS NOT CENTERED ON THE WELD AXIS

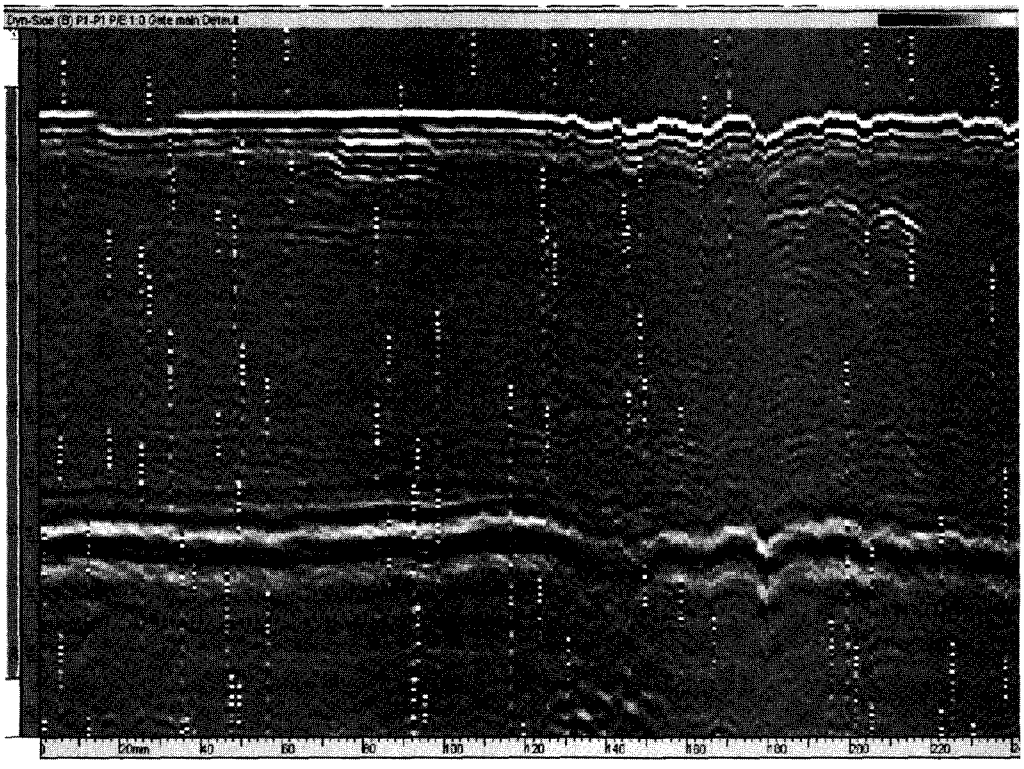


FIG. N-483(h) TOFD IMAGE SHOWING ELECTRICAL NOISE INTERFERENCE

signal. These S-S waves may show additional and confirmatory information. The diffracted shear waves show the porosity more clearly than the diffracted longitudinal waves and there is a strong mode-converted signal that occurs just before the shear wave gate, which could cause interpretation problems. Normally, the gate is set fairly short to enclose only the lateral wave and the longitudinal wave backwall to clarify interpretation.

(e) Incorrect (too far apart) transducer separation [Fig. N-483(e)] results in the backwall signal becoming distorted, the lateral wave becomes weaker, and some of the diffracted signal amplitudes drop.

(f) Incorrect (too close together) transducer separation [Fig. N-483(f)] results in the lateral waves becoming stronger, and the backwall weaker. Again, the TOFD image of the flaws is poor.

(g) If the transducers are not centered on the weld [Fig. N-483(g)], the diffracted signal amplitudes will decline to the point where flaw detection is seriously impaired.

(h) Noise levels [Fig. N-483(h)] can seriously impair TOFD interpretation. Noise can come from a number of sources such as electrical, ultrasonic, grains, and coupling. Typically, ultrasonic and grain noise appears universally across the TOFD image. Electrical noise appears as an interference pattern, depending on the noise source. Once the occurrence of the electrical noise increases beyond a certain point, interpretation becomes essentially impossible.

ARTICLE 5
ULTRASONIC EXAMINATION METHODS FOR MATERIALS

04

T-510 SCOPE

This Article provides or references requirements, which are to be used in selecting and developing ultrasonic examination procedures for parts, components, materials, and all thickness determinations. When SA, SB, and SE documents are referenced, they are located in Article 23. The referencing Code Section shall be consulted for specific requirements for the following:

(a) personnel qualification/certification requirements;

(b) procedure requirements/demonstration, qualification, acceptance;

(c) examination system characteristics;

(d) retention and control of calibration blocks;

(e) extent of examination and/or volume to be scanned;

(f) acceptance standards;

(g) retention of records, and

(h) report requirements.

Definitions of terms used in this Article are contained in Mandatory Appendix III of this Article.

T-520 GENERAL

T-521 Basic Requirements

The requirements of this article shall be used together with Article 1, General Requirements.

T-522 Written Procedure Requirements

T-522.1 Requirements. Ultrasonic examination shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-522. The written procedure shall establish a single value, or range of values, for each requirement.

T-522.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-522 identified as an *essential variable* from the specified value, or range of values, shall require requalification of the written procedure. A change of a requirement identified as a *nonessential variable* from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

T-530 EQUIPMENT

T-531 Instrument

A pulse-echo type of ultrasonic instrument shall be used. The instrument shall be capable of operation at frequencies over the range of at least 1 MHz to 5 MHz, and shall be equipped with a stepped gain control in units of 2.0 dB or less. If the instrument has a damping control, it may be used if it does not reduce the sensitivity of the examination. The reject control shall be in the "off" position for all examinations unless it can be demonstrated that it does not affect the linearity of the examination.

T-532 Search Units

The nominal frequency shall be from 1 MHz to 5 MHz unless variables such as production material grain structure require the use of other frequencies to assure adequate penetration or better resolution. Search units with contoured contact wedges may be used to aid ultrasonic coupling.

T-533 Couplant

T-533.1 General. The couplant, including additives, shall not be detrimental to the material being examined.

T-533.2 Control of Contaminants

(a) Couplants used on nickel base alloys shall not contain more than 250 ppm of sulfur.

(b) Couplants used on austenitic stainless steel or titanium shall not contain more than 250 ppm of halides (chlorides plus fluorides).

TABLE T-522
VARIABLES OF AN ULTRASONIC EXAMINATION PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Material types and configurations to be examined, including thickness dimensions and product form (castings, forgings, plate, etc.)	X	
Personnel qualification requirements		X
Personnel performance requirements, when required	X	
The surfaces from which the examination shall be performed	X	
Surface condition (examination surface, calibration block)		X
Couplant: brand name or type		X
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	
Angle(s) and mode(s) of wave propagation in the material	X	
Search unit type(s), frequency(ies), and element size(s) shape(s)	X	
Special search units, wedges, shoes, or saddles, when used	X	
Ultrasonic instrument(s)	X	
Calibration [calibration block(s) and technique(s)]	X	
Directions and extent of scanning	X	
Automatic alarm and/or recording equipment, when applicable		X
Scanning (manual vs. automatic)	X	
Method for sizing indications	X	
Computer enhanced data acquisition, when used	X	
Records, including minimum calibration data to be recorded (e.g., instrument settings)		X
Scan overlap (decrease only)	X	

T-534 Calibration Block Requirements

The material from which the block is fabricated shall be of the same product form, material specification or equivalent P-Number grouping, and heat treatment as the material being examined. For the purposes of this paragraph, P-Nos. 1, 3, 4, and 5 materials are considered equivalent. The finish on the scanning surface of the block shall be representative of the scanning surface finish on the material to be examined.

T-534.1 Tubular Product Calibration Blocks

(a) The calibration reflectors shall be longitudinal (axial) notches and shall have a length not to exceed 1 in. (25 mm), a width not to exceed $\frac{1}{16}$ in. (1.5 mm), and depth not to exceed 0.004 in. (0.10 mm) or 5% of the nominal wall thickness, whichever is larger.

(b) The calibration block shall be long enough to simulate the handling of the product being examined through the examination equipment.

T-534.2 Casting Calibration Blocks. Calibration blocks shall be the same thickness ±25% as the casting to be examined.

T-534.3 Bolting[1] Material Calibration Blocks and Examination Techniques. Calibration blocks in accordance with Fig. T-534.3 shall be used for straight beam examination.

[1] "Bolting" as used in this Article is an all-inclusive term for any type of threaded fastener that may be used in a pressure boundary bolted flange joint assembly such as a bolt, stud, studbolt, cap screw, etc.

T-560 CALIBRATION

T-561 Instrument Linearity Checks A06

The requirements of T-561.1 and T-561.2 shall be met at intervals not to exceed three months for analog type instruments and one year for digital type instruments, or prior to first use thereafter.

T-561.1 Screen Height Linearity. The ultrasonic instrument's (excludes instruments used for thickness measurement) screen height linearity shall be evaluated in accordance with Mandatory Appendix I of Article 4.

T-561.2 Amplitude Control Linearity. The ultrasonic instrument's (excludes instruments used for thickness measurement) amplitude control linearity shall be evaluated in accordance with Mandatory Appendix II of Article 4.

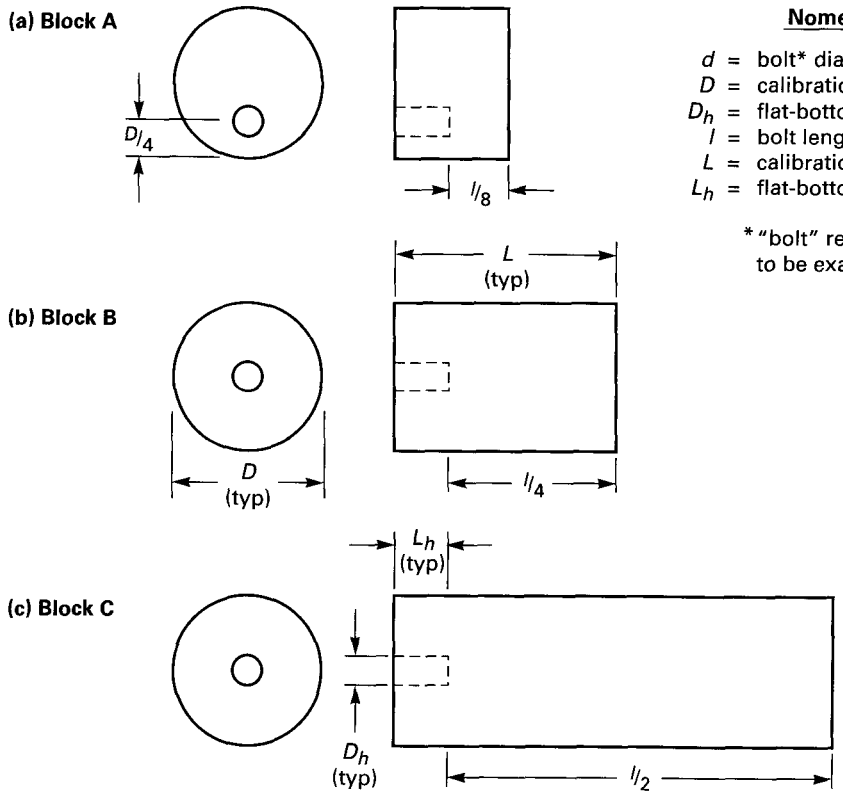
T-562 General Calibration Requirements

T-562.1 Ultrasonic System. Calibrations shall include the complete ultrasonic system and shall be performed prior to use of the system in the thickness range under examination.

T-562.2 Calibration Surface. Calibrations shall be performed from the surface (clad or unclad; convex or concave) corresponding to the surface of the material from which the examination will be performed.

T-562.3 Couplant. The same couplant to be used during the examination shall be used for calibration.

FIG. T-534.2.1 DELETED A06



Nomenclature

d = bolt* diameter
D = calibration block diameter
D_h = flat-bottom hole diameter
l = bolt length
L = calibration block length
L_h = flat-bottom hole length

* "bolt" refers to the material to be examined (bolting)

Diameter of Bolting Material to be Examined (d)	Calibration Block Diameter (D)	Flat-Bottom Hole Diameter (D_h)
Up to 1 in. (25 mm)	$d \pm d/4$	1/16 in. (1.5 mm)
Over 1 in. (25 mm) to 2 in. (50 mm)	$d \pm d/4$	1/8 in. (3 mm)
Over 2 in. (50 mm) to 3 in. (75 mm)	$d \pm d/4$	3/16 in. (5 mm)
Over 3 in. (75 mm) to 4 in. (100 mm)	$d \pm d/4$	5/16 in. (8 mm)
Over 4in. (100 mm)	$d \pm$ 1 in. (25 mm)	3/8 in. (10 mm)

Calibration Block Designation	Flat-Bottom Hole Depth (L_h)
A	1.5 in. (38 mm)
B	0.5 in. (13 mm)
C	0.5 in. (13 mm)

GENERAL NOTE: A tolerance of ±5% may be applied.

FIG. T-534.3 STRAIGHT BEAM CALIBRATION BLOCKS FOR BOLTING

T-562.4 Contact Wedges. The same contact wedges to be used during the examination shall be used for calibration.

T-562.5 Instrument Controls. Any control, which affects instrument linearity (e.g., filters, reject, or clipping), shall be in the same position for calibration, calibration checks, instrument linearity checks, and examination.

T-562.6 Temperature. For contact examination, the temperature differential between the calibration block and examination surfaces shall be within 25°F (14°C). For immersion examination, the couplant temperature for calibration shall be within 25°F (14°C) of the couplant temperature for examination.

T-563 Calibration Confirmation

T-563.1 System Changes. When any part of the examination system is changed, a calibration check shall be made on the calibration block to verify that distance range points and sensitivity setting(s) satisfy the requirements of T-563.3.

T-563.2 Periodic Examination Checks. A calibration check on at least one of the reflectors in the calibration block or a check using a simulator shall be made at the finish of each examination or series of similar examinations, every 4 hr during the examination, and when examination personnel (except for automated equipment) are changed. The distance range points and sensitivity setting(s) recorded shall satisfy the requirements of T-563.3.

T-563.2.1 Simulator Checks. Any simulator checks that are used shall be correlated with the original calibration on the calibration block during the original calibration. The simulator checks may use different types of calibration reflectors or blocks (such as IIW) and/or electronic simulation. However, the simulation used shall be identifiable on the calibration sheet(s). The simulator check shall be made on the entire examination system. The entire system does not have to be checked in one operation; however, for its check, the search unit shall be connected to the ultrasonic instrument and checked against a calibration reflector. Accuracy of the simulator checks shall be confirmed, using the calibration block, every three months or prior to first use thereafter.

T-563.3 Confirmation Acceptance Values

T-563.3.1 Distance Range Points. If any distance range point has moved on the sweep line by more than 10% of the distance reading or 5% of full sweep (whichever is greater), correct the distance range calibration and note the correction in the examination record. All recorded indications since the last valid calibration or calibration check shall be reexamined and their values shall be changed on the data sheets or re-recorded.

T-563.3.2 Sensitivity Settings. If any sensitivity setting has changed by more than 20% or 2 dB of its amplitude, correct the sensitivity calibration and note the correction in the examination record. If the sensitivity setting has decreased, all data sheets since the last valid calibration or calibration check shall be marked void and the area covered by the voided data shall be reexamined. If the sensitivity setting has increased, all recorded indications since the last valid calibration or calibration check shall be reexamined and their values shall be changed on the data sheets or re-recorded.

T-564 Casting Calibration for Supplementary Angle Beam Examinations

For supplementary angle-beam examinations, the instrument gain shall be adjusted during calibration such that the indication from the side-drilled hole producing the highest amplitude is 80% ±5% of full screen height. This shall be the primary reference level.

T-570 EXAMINATION

T-571 Examination of Product Forms

T-571.1 Plate. Plate shall be examined in accordance with SA-435/SA-435M, SA-577/SA-577M, SA-578/SA-578M, or SB-548, as applicable, except as amended by the requirements elsewhere in this Article.

T-571.2 Forgings and Bars

(a) Forgings and bars shall be examined in accordance with SA-388/SA-388M or SA-745/SA-745M, as applicable, except as amended by the requirements elsewhere in this Article.

(b) All forgings and bars shall be examined by the straight-beam examination technique.

(c) In addition to *(b)* above, ring forgings and other hollow forgings shall also be examined by the angle-beam examination technique in two circumferential directions, unless wall thickness or geometric configuration makes angle-beam examination impractical.

(d) In addition to *(b)* and *(c)* above, ring forgings made to fine grain melting practices and used for vessel shell sections shall be also examined by the angle-beam examination technique in two axial directions.

(e) Immersion techniques may be used.

T-571.3 Tubular Products. Tubular products shall be examined in accordance with SE-213 or SE-273, as applicable, except as amended by the requirements elsewhere in this Article.

T-571.4 Castings. Castings shall be examined in accordance with SA-609/SA-609M, except as amended by the requirements elsewhere in this Article.

(a) For straight-beam examinations, the sensitivity compensation in paragraph 8.3 of SA-609/SA-609M shall not be used.

(b) A supplementary angle-beam examination shall be performed on castings or areas of castings where a back reflection cannot be maintained during straight-beam examination, or where the angle between the front and back surfaces of the casting exceeds 15 deg.

T-571.5 Bolting Material. Bolting material shall be examined in accordance with SA-388/SA-388M, except as amended by the requirements elsewhere in this Article.

(a) Bolting material shall be examined radially prior to threading. Sensitivity shall be established using the indication from the side of the hole in calibration block A at radial metal paths of $^{D}/_{4}$ and $^{3D}/_{4}$. The instrument gain shall be adjusted such that the indication from the $^{D}/_{4}$ or $^{3D}/_{4}$ hole (whichever has the highest indication amplitude) is 80% ±5% of full screen height (FSH). This shall be the primary reference level. A distance-amplitude correction (DAC) curve shall be established using the indications from the $^{D}/_{4}$ and $^{3D}/_{4}$ holes and shall be extended to cover the full diameter of the material being examined.

(b) Bolting material shall be examined axially from both end surfaces, either before or after threading. The instrument gain shall be adjusted such that the indication from the flat-bottom hole producing the highest indication amplitude, is 80% ±5% FSH. This shall be the primary reference level. A DAC curve shall be established using the indications from the three flat-bottom holes and shall be extended to cover the full length of the material being examined. If any flat-bottom hole indication amplitude is less than 20% FSH, construct two DAC lines using calibration blocks A and B, and calibration blocks B and C and record the gain setting necessary to adjust the highest indication amplitude for each DAC to 80% ±5% FSH.

(c) Immersion techniques may be used.

T-572 Examination of Pumps and Valves

Ultrasonic examination of pumps and valves shall be in accordance with Mandatory Appendix I.

T-573 Inservice Examination

T-573.1 Nozzle Inner Radius and Inner Corner Region. Inservice examination of nozzle inner radii and inner corner regions shall be in accordance with Mandatory Appendix II.

T-573.2 Inservice Examination of Bolting. Inservice examination of bolting shall be in accordance with Mandatory Appendix IV.

T-573.3 Inservice Examination of Cladding. Inservice examination of cladding, excluding weld metal overlay cladding, shall be in accordance with SA-578/SA-578M.

T-574 Thickness Measurement

Thickness measurement shall be performed in accordance with SE-797, except as amended by the requirements elsewhere in this Article.

T-580 EVALUATION

For examinations using DAC calibrations, any imperfection with an indication amplitude in excess of 20% of DAC shall be investigated to the extent that it can be evaluated in terms of the acceptance criteria of the referencing Code Section.

T-590 DOCUMENTATION

T-591 Recording Indications

T-591.1 Non-Rejectable Indications. Non-rejectable indications shall be recorded as specified by the referencing Code Section.

T-591.2 Rejectable Indications. Rejectable indications shall be recorded. As a minimum, the type of indication (i.e., crack, lamination, inclusion, etc.), location, and extent (i.e., length) shall be recorded.

T-592 Examination Records

For each ultrasonic examination, the following information shall be recorded:

(a) procedure identification and revision;

(b) ultrasonic instrument identification (including manufacturer's serial number);

(c) search unit(s) identification (including manufacturer's serial number, frequency, and size);

(d) beam angle(s) used;

(e) couplant used, brand name or type;

(f) search unit cable(s) used, type and length;

(g) special equipment, when used (search units, wedges, shoes, automatic scanning equipment, recording equipment, etc.);

(h) computerized program identification and revision, when used;

(i) calibration block identification;

(j) simulation block(s) and electronic simulator(s) identification, when used;

(k) instrument reference level gain and, if used, damping and reject setting(s);

(l) calibration data [including reference reflector(s), indication amplitude(s), and distance reading(s)];

(m) data correlating simulation block(s) and electronic simulator(s), when used, with initial calibration;

(n) identification of material or volume scanned;

(o) surface(s) from which examination was conducted, including surface condition;

(p) map or record of rejectable indications detected or areas cleared;

(q) areas of restricted access or inaccessible areas;

(r) examination personnel identity and, when required by referencing Code Section, qualification level;

(s) date of examination. A06

Items *(b)* through *(m)* may be included in a separate calibration record provided the calibration record identification is included in the examination record.

T-593 Report

A report of the examinations shall be made. The report shall include those records indicated in T-591 and T-592. The report shall be filed and maintained in accordance with the referencing Code Section.

ARTICLE 5
MANDATORY APPENDICES

APPENDIX I — ULTRASONIC EXAMINATION OF PUMPS AND VALVES

I-510 SCOPE

This Appendix describes supplementary requirements to Article 5 for ultrasonic examination of welds or base material repairs, or both, in pumps and valves.

I-530 EQUIPMENT

I-531 Calibration Blocks

Calibration blocks for pumps and valves shall be in accordance with Article 4, Nonmandatory Appendix J.

I-560 CALIBRATION

I-561 System Calibration

System calibration shall be in accordance with Article 4, T-463 exclusive of T-463.1.1.

I-570 EXAMINATION

The examination shall be in accordance with Article 4, T-470.

APPENDIX II — INSERVICE EXAMINATION OF NOZZLE INSIDE CORNER RADIUS AND INNER CORNER REGIONS

II-510 SCOPE

This Appendix describes supplementary requirements to Article 5 for inservice examination of nozzle inside corner radius and inner corner regions.

II-530 EQUIPMENT

II-531 Calibration Blocks

Calibration blocks shall be full-scale or partial-section (mockup) nozzles, which are sufficient to contain the maximum sound beam path, examination volume, and calibration reflectors.

II-531.1 General. The general calibration block requirements of Article 4, T-434.1 shall apply.

II-531.2 Mockups. If sound beams only pass through nozzle forgings during examinations, nozzle mockups may be nozzle forgings, or segments of forgings, fixed in structures as required to simulate adjacent vessel surfaces. If sound beams pass through nozzle-to-shell welds during examinations, nozzle mockups shall contain nozzle welds and shell components of sufficient size to permit calibration.

II-531.3 Thickness. The calibration block shall equal or exceed the maximum component thickness to be examined.

II-531.4 Reflectors. The calibration block shall contain a minimum of three notches within the examination volume. Alternatively, induced or embedded cracks may be used in lieu of notches, which may also be employed for demonstration of sizing capabilities when required by the referencing Code Section. Notches or cracks shall meet the following requirements:

(a) Notches or cracks shall be distributed radially in two zones with at least one notch or crack in each zone. Zone 1 ranges between 0 deg and 180 deg (±45 deg) and Zone 2 is the remaining two quadrants, centered on the nozzle's axis.

(b) Axial and circumferential notches or cracks shall be placed with the nozzle inner radii examination volume; the orientation tolerance ±2 deg.

(c) Notch or crack lengths shall be 1 in. (25 mm) maximum. Nominal notch widths shall be $\frac{1}{16}$ in. (1.5 mm).

(d) Notch or crack depths, measured from the nozzle inside surface, shall be:

(1) Reflector No. 1 – 0.20 in. to 0.35 in. (5 mm to 9 mm)

(2) Reflector No. 2 – 0.35 in. to 0.55 in. (9 mm to 14 mm)

(3) Reflector No. 3 – 0.55 in. to 0.75 in. (14 mm to 19 mm)

II-560 CALIBRATION

II-561 System Calibration

System calibration shall be in accordance with Article 4, T-463 exclusive of T-463.1.1.

II-570 EXAMINATION

The general examination requirements of Article 4, T-471 shall apply.

APPENDIX III — GLOSSARY OF TERMS FOR ULTRASONIC EXAMINATION

III-510 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms related to Ultrasonic Examination.

III-520 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section I provides the definitions of terms listed in III-530(a).

(c) For general terms, such as *Interpretation, Flaw, Discontinuity, Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph III-530(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

III-540 MISCELLANEOUS REQUIREMENTS

A06 *(a)* The following SE-1316 terms are used in conjunction with this Article: A-scan; amplitude; angle beam; attenuation; attenuator; B-scan presentation; back reflection; base line; beam spread; C-scan; contact testing; couplant; damping, search unit; decibel (dB); distance amplitude response curve; dual search unit; echo; frequency (inspection); frequency (pulse repetition); holography (acoustic); immersion testing; indication; initial pulse; interface; linearity (amplitude); linearity (time or distance); longitudinal wave; loss of back reflection; mode; noise; pulse; pulse echo method; pulse repetition rate; range; reference block; reflector; reject (suppression); resolution; scanning; search unit; sensitivity; shear wave; signal-to-noise ratio; straight beam; sweep; test surface; through transmission technique; transducer; ultrasonic; vee path; video presentation; wedge.

(b) The following Code terms are used in conjunction with this Article: A06

alternative reflector — a reflector, other than the specified reflector, whose ultrasonic response has been adjusted to be equal to or greater than the response from the specified reflector at the same sound path distance in the basic calibration block

axial direction — direction of sound beam parallel to component's major axis

calibration — correlation of the ultrasonic system response(s) with calibration reflector(s)

calibration reflector — a reflector with a dimensioned surface which is used to provide an accurately reproducible reference level

circumferential direction — direction of sound beam perpendicular to (cylindrical) component's major axis

clipping — see *reject*

computerized imaging — computer processed display or analysis and display of ultrasonic data to provide two- or three-dimensional images of reflectors

CRT — cathode ray tube

Distance Amplitude Correction (DAC) curve — see *distance amplitude response curve*

D-scan — an ultrasonic data presentation which provides an end view of the specimen indicating the approximate width (as detected per scan) of reflectors and their relative positions

dynamic calibration — calibration that is conducted with the search unit in motion, usually at the same speed and direction of the actual test examination

electric simulator — an electronic device that enables correlation of ultrasonic system response initially obtained employing the basic calibration block

examination system — a system that includes the ultrasonic instrument, search unit cable, and search unit

multiple back reflections — in ultrasonic straight beam examination, successive reflections from the back and front surfaces of the material

piezoelectric element — crystal or polycrystal materials which when mechanically deformed, produce electrical charges, and conversely, when intermittently charged, will deform and produce mechanical vibrations

primary reference response (level) — the ultrasonic response from the basic calibration reflector at the specified sound path distance, electronically adjusted to a specified percentage of the full screen height

refraction — the angular change in direction of the ultrasonic beam as it passes obliquely from one medium to another, in which the waves have a different velocity

ringing time — the time that the mechanical vibrations of a piezoelectric element continue after the electrical pulse has stopped

scanning surface — see *test surface*

simulation block — a reference block or other item in addition to the basic calibration block that enables correlation of ultrasonic system response initially obtained when using the basic calibration block

SAFT-UT — Synthetic Aperture Focusing Technique for ultrasonic testing

static calibration — calibration for examination wherein the search unit is positioned on a calibration block so that the pertinent reflectors can be identified and the instrumentation adjusted accordingly

(c) The following definitions are used in conjunction with Article 4, Appendix L:

acoustic pulse — the duration of time between the start and end of the signal when the amplitude reaches 10% of the maximum amplitude

B-scan (parallel scan) — scan that shows the data collected when scanning the transducer pair in the direction of the sound beam transversely across a weld

back-wall signal — sound wave that travels between the two transducers with a longitudinal velocity that reflects off the materials back surface

D-scan (non-parallel scan) — scan that shows the data collected when scanning the transducer pair perpendicular to the direction of the sound beam along a weld

diffracted signals — diffracted waves from the upper and lower tips of flaws resulting from its interaction with the incident sound wave

free-run — recording a set of data without moving the search-units

lateral wave — sound wave that travels directly between the transducers with a longitudinal velocity just below the surface of the material

time-of-flight — the time it takes for a sound wave to travel from the transmitting transducer to the flaw, and then to the receiving transducer

A06 *(d)* The following definitions are used in conjunction with Article 4, Mandatory Appendix III:

back-wall echo — a specular reflection from the back-wall of the component being examined

diffraction — when a wave front direction has been changed by an obstacle or other in-homogeneity in a medium, other than by reflection or refraction

free run — taking data, without the movement of the probes (e.g., held stationary), of the lateral wave and back-wall reflection to check system software output

lateral wave — a compression wave that travels by the most direct route from the transmitting probe to the receiving probe in a TOFD configuration

nonparallel or longitudinal scan — a scan whereby the probe pair motion is perpendicular to the ultrasonic beam (e.g., parallel to the weld axis)

parallel or transverse scan — a scan whereby the probe pair motion is parallel to the ultrasonic beam (e.g., perpendicular to the weld axis)

probe center spacing (PCS) — the distance between the marked exit points of a pair of TOFD probes for a specific application

TOFD display — a cross-sectional grayscale view of the weld formed by the stacking of the digitized incremental A-scan data. The two types of scans (parallel and non-parallel) are differentiated from each other by calling one a B-scan and the other a D-scan. Currently there is no standardized terminology for these scans and they may be interchanged by various manufacturers (e.g., one calling the scan parallel to the weld axis a B-scan and another a D-scan).

APPENDIX IV — INSERVICE EXAMINATION OF BOLTS

IV-510 SCOPE

This Appendix describes supplementary requirements to Article 5 for inservice examination of bolts.

IV-530 EQUIPMENT

IV-531 Calibration Blocks

Calibration blocks shall be full-scale or partial-section bolts, which are sufficient to contain the maximum sound beam path and area of interest, and to demonstrate the scanning technique.

IV-531.1 Material. The calibration block shall be of the same material specification, product form, and surface finish as the bolt(s) to be examined.

IV-531.2 Reflectors. Calibration reflectors shall be straight-cut notches. A minimum of two notches shall be machined in the calibration standard, located at the minimum and maximum metal paths, except that notches need not be located closer than one bolt diameter from either end. Notch depths shall be as follows:

Bolt Size	Notch Depth*
Less than 2 in. (50 mm)	1 thread depth
2 in. (50 mm) and greater, but less than 3 in. (75 mm)	$\frac{5}{64}$ in. (2.0 mm)
3 in. (75 mm) and greater	$\frac{3}{32}$ in. (2.5 mm)

*Measured from bottom of thread root to bottom of notch.

As an alternative to straight-cut notches, other notches (e.g., circular cut) may be used provided the area of the notch does not exceed the area of the applicable straight-cut notches required by this paragraph.

IV-560 CALIBRATION

A06 **IV-561 DAC Calibration**

A DAC curve shall be established using the calibration reflectors in IV-531.2. The sound beam shall be directed toward the calibration reflector that yields the maximum response, and the instrument shall be set to obtain an 80% of full screen height indication. This shall be the primary reference level. The search unit shall then be manipulated, without changing instrument settings, to obtain the maximum responses from the other calibration reflector(s) to generate a DAC curve. The calibration shall establish both the sweep range calibration and the distance amplitude correction.

IV-570 EXAMINATION

IV-571 General Examination Requirements

The general examination requirements of Article 4, T-471 shall apply.

ARTICLE 6
LIQUID PENETRANT EXAMINATION

T-610 SCOPE

When specified by the referencing Code Section, the liquid penetrant examination techniques described in this Article shall be used. In general, this Article is in conformance with SE-165, Standard Test Method for Liquid Penetrant Examination. This document provides details to be considered in the procedures used.

When this Article is specified by a referencing Code Section, the liquid penetrant method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article appear in Mandatory Appendix I of this Article and Article 1, Appendix I.

T-620 GENERAL

The liquid penetrant examination method is an effective means for detecting discontinuities which are open to the surface of nonporous metals and other materials. Typical discontinuities detectable by this method are cracks, seams, laps, cold shuts, laminations, and porosity.

In principle, a liquid penetrant is applied to the surface to be examined and allowed to enter discontinuities. All excess penetrant is then removed, the part is dried, and a developer is applied. The developer functions both as a blotter to absorb penetrant that has been trapped in discontinuities, and as a contrasting background to enhance the visibility of penetrant indications. The dyes in penetrants are either color contrast (visible under white light) or fluorescent (visible under ultraviolet light).

T-621 Written Procedure Requirements

T-621.1 Requirements. Liquid penetrant examination shall be performed in accordance with a written procedure which shall as a minimum, contain the requirements listed in Table T-621. The written procedure shall establish a single value, or range of values, for each requirement.

A05 **T-621.2 Procedure Qualification.** When procedure qualification is specified, a change of a requirement in Table T-621 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-630 EQUIPMENT

The term *penetrant materials,* as used in this Article, is intended to include all penetrants, emulsifiers, solvents or cleaning agents, developers, etc., used in the examination process. The descriptions of the liquid penetrant classifications and material types are provided in SE-165 of Article 24.

T-640 MISCELLANEOUS REQUIREMENTS

T-641 Control of Contaminants 04

The user of this Article shall obtain certification of contaminant content for all liquid penetrant materials used on nickel base alloys, austenitic or duplex stainless steels, and titanium. These certifications shall include the penetrant manufacturers' batch numbers and the test results obtained in accordance with Mandatory Appendix II of this Article. These records shall be maintained as required by the referencing Code Section.

T-642 Surface Preparation

(a) In general, satisfactory results may be obtained when the surface of the part is in the as-welded, as-rolled, as-cast, or as-forged condition. Surface preparation by grinding, machining, or other methods may be necessary where surface irregularities could mask indications.

(b) Prior to each liquid penetrant examination, the surface to be examined and all adjacent areas within at least

TABLE T-621
REQUIREMENTS OF A LIQUID PENETRANT EXAMINATION PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Identification of and any change in type or family group of penetrant materials including developers, emulsifiers, etc.	X	...
Surface preparation (finishing and cleaning, including type of cleaning solvent)	X	...
Method of applying penetrant	X	...
Method of removing excess surface penetrant	X	...
Hydrophilic or lipophilic emulsifier concentration and dwell time in dip tanks and agitation time for hydrophilic emulsifiers	X	...
Hydrophilic emulsifier concentration in spray applications	X	...
Method of applying developer	X	...
Minimum and maximum time periods between steps and drying aids	X	...
Decrease in penetrant dwell time	X	...
Increase in developer dwell time (Interpretation Time)	X	...
Minimum light intensity	X	...
Surface temperature outside 50 to 125°F (10 to 52°C) or as previously qualified	X	...
Performance demonstration, when required	X	...
Personnel qualification requirements	...	X
Materials, shapes, or sizes to be examined and the extent of examination	...	X
Post-examination cleaning technique	...	X

1 in. (25 mm) shall be dry and free of all dirt, grease, lint, scale, welding flux, weld spatter, paint, oil, and other extraneous matter that could obscure surface openings or otherwise interfere with the examination.

(c) Typical cleaning agents which may be used are detergents, organic solvents, descaling solutions, and paint removers. Degreasing and ultrasonic cleaning methods may also be used.

(d) Cleaning solvents shall meet the requirements of T-641. The cleaning method employed is an important part of the examination process.

NOTE: Conditioning of surfaces prior to examination as required in T-642(a) may affect the results. See SE-165, Annex A1.

T-643 Drying After Preparation

After cleaning, drying of the surfaces to be examined shall be accomplished by normal evaporation or with forced hot or cold air. A minimum period of time shall be established to ensure that the cleaning solution has evaporated prior to application of the penetrant.

T-650 TECHNIQUE

T-651 Techniques

Either a color contrast (visible) penetrant or a fluorescent penetrant shall be used with one of the following three penetrant processes:

(a) water washable
(b) post-emulsifying
(c) solvent removable

The visible and fluorescent penetrants used in combination with these three penetrant processes result in six liquid penetrant techniques.

T-652 Techniques for Standard Temperatures

As a standard technique, the temperature of the penetrant and the surface of the part to be processed shall not be below 50°F (10°C) nor above 125°F (52°C) throughout the examination period. Local heating or cooling is permitted provided the part temperature remains in the range of 50°F to 125°F (10°C to 52°C) during the examination. Where it is not practical to comply with these temperature limitations, other temperatures and times may be used, provided the procedures are qualified as specified in T-653.

T-653 Techniques for Nonstandard Temperatures

When it is not practical to conduct a liquid penetrant examination within the temperature range of 50°F to 125°F (10°C to 52°C), the examination procedure at the proposed lower or higher temperature range requires qualification of the penetrant materials and processing in accordance with Mandatory Appendix III of this Article.

TABLE T-672 MINIMUM DWELL TIMES

Material	Form	Type of Discontinuity	Dwell Times [Note (1)] (minutes) Penetrant	Developer
Aluminum, magnesium, steel, brass and bronze, titanium and high-temperature alloys	Castings and welds	Cold shuts, porosity, lack of fusion, cracks (all forms)	5	10
	Wrought materials — extrusions, forgings, plate	Laps, cracks (all forms)	10	10
Carbide-tipped tools		Lack of fusion, porosity, cracks	5	10
Plastic	All forms	Cracks	5	10
Glass	All forms	Cracks	5	10
Ceramic	All forms	Cracks	5	10

NOTE:
(1) For temperature range from 50°F to 125°F (10°C to 52°C).

T-654 Technique Restrictions

Fluorescent penetrant examination shall not follow a color contrast penetrant examination. Intermixing of penetrant materials from different families or different manufacturers is not permitted. A retest with water washable penetrants may cause loss of marginal indications due to contamination.

T-660 CALIBRATION

Light meters, both visible and fluorescent (black) light meters, shall be calibrated at least once a year or whenever the meter has been repaired. If meters have not been in use for one year or more, calibration shall be done before being used.

T-670 EXAMINATION

T-671 Penetrant Application

The penetrant may be applied by any suitable means, such as dipping, brushing, or spraying. If the penetrant is applied by spraying using compressed-air-type apparatus, filters shall be placed on the upstream side near the air inlet to preclude contamination of the penetrant by oil, water, dirt, or sediment that may have collected in the lines.

T-672 Penetration (Dwell) Time

Penetration (dwell) time is critical. The minimum penetration time shall be as required in Table T-672 or as qualified by demonstration for specific applications.

T-673 Excess Penetrant Removal

After the specified penetration (dwell) time has elapsed, any penetrant remaining on the surface shall be removed, taking care to minimize removal of penetrant from discontinuities.

T-673.1 Water-Washable Penetrants. Excess water-washable penetrant shall be removed with a water spray. The water pressure shall not exceed 50 psi (350 kPa), and the water temperature shall not exceed 110°F (43°C).

T-673.2 Postemulsification Penetrants

(a) Lipophilic Emulsification. After the required penetrant dwell time, the excess surface penetrant shall be emulsified by immersing or flooding the part with the emulsifier. Emulsification time is dependent on the type of emulsifier and surface condition. The actual emulsification time shall be determined experimentally. After emulsification, the mixture shall be removed by immersing in or rinsing with water. The temperature and pressure of the water shall be as recommended by the manufacturer.

(b) Hydrophilic Emulsification. After the required penetrant dwell time and prior to emulsification, the parts shall be prerinsed with water spray using the same process as for water-washable penetrants. Prerinsing time shall not exceed 1 min. After prerinsing, the excess surface penetrant shall be emulsified by immersing in or spraying with hydrophilic emulsifier. Bath concentration shall be as recommended by the manufacturer. After emulsification, the mixture shall be removed by immersing in or rinsing with water. The temperature and pressure of the water shall be as recommended by the manufacturer.

NOTE: Additional information may be obtained from SE-165.

T-673.3 Solvent Removable Penetrants. Excess solvent removable penetrants shall be removed by wiping with a cloth or absorbent paper, repeating the operation until most traces of penetrant have been removed. The remaining traces shall be removed by lightly wiping the

surface with cloth or absorbent paper moistened with solvent. To minimize removal of penetrant from discontinuities, care shall be taken to avoid the use of excess solvent. **Flushing the surface with solvent, following the application of the penetrant and prior to developing, is prohibited.**

T-674 Drying After Excess Penetrant Removal

(a) For the water washable or post-emulsifying technique, the surfaces may be dried by blotting with clean materials or by using circulating air, provided the temperature of the surface is not raised above 125°F (52°C).

(b) For the solvent removable technique, the surfaces may be dried by normal evaporation, blotting, wiping, or forced air.

T-675 Developing

The developer shall be applied as soon as possible after penetrant removal; the time interval shall not exceed that established in the procedure. Insufficient coating thickness may not draw the penetrant out of discontinuities; conversely, excessive coating thickness may mask indications.

With color contrast penetrants, only a wet developer shall be used. With fluorescent penetrants, a wet or dry developer may be used.

T-675.1 Dry Developer Application. Dry developer shall be applied only to a dry surface by a soft brush, hand powder bulb, powder gun, or other means, provided the powder is dusted evenly over the entire surface being examined.

T-675.2 Wet Developer Application. Prior to applying suspension type wet developer to the surface, the developer must be thoroughly agitated to ensure adequate dispersion of suspended particles.

(a) Aqueous Developer Application. Aqueous developer may be applied to either a wet or dry surface. It shall be applied by dipping, brushing, spraying, or other means, provided a thin coating is obtained over the entire surface being examined. Drying time may be decreased by using warm air, provided the surface temperature of the part is not raised above 125°F (52°C). Blotting is not permitted.

(b) Nonaqueous Developer Application. Nonaqueous developer shall be applied only to a dry surface. It shall be applied by spraying, except where safety or restricted access preclude it. Under such conditions, developer may be applied by brushing. Drying shall be by normal evaporation.

T-675.3 Developing time for final interpretation begins immediately after the application of a dry developer or as soon as a wet developer coating is dry. The minimum developing time shall be as required by Table T-672.

T-676 Interpretation

T-676.1 Final Interpretation. Final interpretation shall be made within 10 to 60 min after the requirements of T-675.3 are satisfied. If bleed-out does not alter the examination results, longer periods are permitted. If the surface to be examined is large enough to preclude complete examination within the prescribed or established time, the examination shall be performed in increments.

T-676.2 Characterizing Indication(s). The type of discontinuities are difficult to evaluate if the penetrant diffuses excessively into the developer. If this condition occurs, close observation of the formation of indication(s) during application of the developer may assist in characterizing and determining the extent of the indication(s).

T-676.3 Color Contrast Penetrants. With a color contrast penetrant, the developer forms a reasonably uniform white coating. Surface discontinuities are indicated by bleed-out of the penetrant which is normally a deep red color that stains the developer. Indications with a light pink color may indicate excessive cleaning. Inadequate cleaning may leave an excessive background making interpretation difficult. A minimum light intensity of 100 fc (1000 lx) is required on the surface to be examined to ensure adequate sensitivity during the examination and evaluation of indications. The light source, technique used, and light level verification is required to be demonstrated one time, documented, and maintained on file.

T-676.4 Fluorescent Penetrants. With fluorescent penetrants, the process is essentially the same as in T-676.3, with the exception that the examination is performed using an ultraviolet light, called *black light.* The examination shall be performed as follows: A05

(a) It shall be performed in a darkened area.

(b) Examiners shall be in a darkened area for at least 5 min prior to performing examinations to enable their eyes to adapt to dark viewing. Glasses or lenses worn by examiners shall not be photosensitive.

(c) Black lights shall achieve a minimum of 1000 $\mu W/cm^2$ on the surface of the part being examined throughout the examination.

(d) Reflectors and filters should be checked and, if necessary, cleaned prior to use. Cracked or broken filters shall be replaced immediately.

(e) The black light intensity shall be measured with a black light meter prior to use, whenever the light's power

source is interrupted or changed, and at the completion of the examination or series of examinations.

T-677 Post-Examination Cleaning

When post-examination cleaning is required by the procedure, it should be conducted as soon as practical after Evaluation and Documentation using a process that does not adversely affect the part.

T-680 EVALUATION

(a) All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

(b) Discontinuities at the surface will be indicated by bleed-out of penetrant; however, localized surface irregularities due to machining marks or other surface conditions may produce false indications.

(c) Broad areas of fluorescence or pigmentation which could mask indications of discontinuities are unacceptable, and such areas shall be cleaned and reexamined.

T-690 DOCUMENTATION

T-691 Recording of Indications

T-691.1 Nonrejectable Indications. Nonrejectable indications shall be recorded as specified by the referencing Code Section.

T-691.2 Rejectable Indications. Rejectable indications shall be recorded. As a minimum, the type of indications (linear or rounded), location and extent (length or diameter or aligned) shall be recorded.

T-692 Examination Records 04

For each examination, the following information shall be recorded:

(a) procedure identification and revision;

(b) liquid penetrant type (visible or fluorescent);

(c) type (number or letter designation) of each penetrant, penetrant remover, emulsifier, and developer used;

(d) examination personnel identity and if required by referencing Code Section, qualification level;

(e) map or record of indications per T-691;

(f) material and thickness;

(g) lighting equipment; and

(h) date of examination. A06

T-693 Performance Demonstration

Performance demonstration, when required by the referencing Code Section, shall be documented.

ARTICLE 6
MANDATORY APPENDICES

APPENDIX I — GLOSSARY OF TERMS FOR LIQUID PENETRANT EXAMINATION

I-610 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms which appear in Article 6, Liquid Penetrant Examination.

I-620 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section G provides the definitions of terms listed in I-630(a).

(c) For general terms, such as *Indication, Flaw, Discontinuity, Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph I-630(b) provides a list of terms and definitions which are in addition to SE-1316 and are Code specific.

I-630 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: black light; bleedout; blotting; clean; contaminant; contrast; developer; developer, aqueous; developer, dry; developer, nonaqueous; developing time; drying time; dwell time; emulsifier; family; fluorescence; overemulsification; penetrant; penetrant comparator; penetrant fluorescent; penetrant, water washable; post-cleaning; post emulsification; precleaning; rinse; solvent remover.

(b) The following Code terms are used in conjunction with this Article:

black light intensity — a quantitative expression of ultraviolet irradiance

color contrast penetrant — a highly penetrating liquid incorporating a nonfluorescent dye which produces indications of such intensity that they are readily visible during examination under white light

post emulsification penetrant — a type of penetrant containing no emulsifier, but which requires a separate emulsifying step to facilitate water rinse removal of the surface penetrant

solvent removable penetrant — a type of penetrant used where the excess penetrant is removed from the surface of the part by wiping using a nonaqueous liquid

ARTICLE 6
MANDATORY APPENDICES

APPENDIX II — CONTROL OF CONTAMINANTS FOR LIQUID PENETRANT EXAMINATION

II-610 SCOPE

This Appendix contains requirements for the control of contaminant content for all liquid penetrant materials used on nickel base alloys, austenitic stainless steels, and titanium.

II-640 REQUIREMENTS

II-641 Nickel Based Alloys

When examining nickel based alloys, all materials shall be analyzed individually for sulfur content as follows.

(a) An individual sample of the penetrant materials with exception of cleaners shall be prepared for analysis by heating 50 g of the material in a 6 in. (150 mm) nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(b) Analysis of the residue shall be as follows: If the residue is less than 0.0025 g, the material is acceptable without further analysis. If the residue is 0.0025 g or more, the procedure shown in (a) above shall be repeated and the residue analyzed in accordance with SD-129 or SD-1552. Alternately, the material may be decomposed in accordance with SD-129 and analyzed in accordance with SD-516 Method B. The sulphur content shall not exceed 1% of the residue by weight.

(c) An individual sample of cleaner/remover material shall be prepared for analysis by heating 100 g of the material in a 6 in. (150 mm) nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(d) Analysis of the residue shall be as follows: If the residue is less than 0.005 g, the material is acceptable without further analysis. If the residue is 0.005 g or more, the procedure shown in (c) above shall be repeated and the residue analyzed in accordance with SD-129 or SD-1552. Alternately the material may be decomposed in accordance with SD-129 and analyzed in accordance with SD-516 Method B. The sulphur content shall not exceed 1% of the residue by weight.

II-642 Austenitic or Duplex Stainless Steel and Titanium 04

When examining austenitic or duplex stainless steel or titanium, all materials shall be analyzed individually for chlorine and fluorine content as follows.

(a) An individual sample of the penetrant materials with the exception of cleaners shall be prepared for analysis by heating 50 g of the material in a 6 in. (150 mm) nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(b) If the residue is 0.0025 g or more, the procedure shown in (a) above shall be repeated. The residue may be analyzed in accordance with SD-808 and the total shall not exceed 1% by weight. Or, alternately, the residue shall be analyzed in accordance with SE-165, Annex 2 for chlorine and SE-165, Annex 3 for fluorine, and the total chlorine plus fluorine content shall not exceed 1% by weight.

(c) An individual sample of the cleaner/remover material shall be prepared for analysis by heating 100 g of the material in a 6 in. (150 mm) nominal diameter glass Petri dish at a temperature of 194°F to 212°F (90°C to 100°C) for 60 min.

PRECAUTION: Provide adequate ventilation to dissipate the emitted vapor.

(d) If the residue is 0.005 g or more, the procedure shown in (c) above shall be repeated. The residue may be analyzed in accordance with SD-808 and the total shall not exceed 1% by weight. Or, alternately, the residue

shall be analyzed in accordance with SE-165, Annex 2 for chlorine and SE-165, Annex 3 for fluorine, and the total chlorine plus fluorine content shall not exceed 1% by weight.

II-643 Alternative

As an alternative to II-641 and II-642 above, SE-165, Annex A4 may be used for determination of anions by ion chromatography, which provides a single instrumental technique for rapid sequential measurement of common anions such as chloride, fluoride, and sulfate.

II-690 DOCUMENTATION

Certifications obtained on penetrant materials shall include the penetrant manufacturers' batch numbers and the test results obtained in accordance with II-640. These records shall be maintained as required by the referencing Code Section.

ARTICLE 6
MANDATORY APPENDICES

APPENDIX III — QUALIFICATION TECHNIQUES FOR EXAMINATIONS AT NONSTANDARD TEMPERATURES

III-610 SCOPE

When a liquid penetrant examination cannot be conducted within the standard temperature range of 50°F to 125°F (10°C to 52°C), the temperature of the examination shall be qualified in accordance with this Appendix.

III-630 MATERIALS

A liquid penetrant comparator block shall be made as follows. The liquid penetrant comparator blocks shall be made of aluminum, ASTM B 209, Type 2024, $^3/_8$ in. (9.5 mm) thick, and should have approximate face dimensions of 2 in. × 3 in. (50 mm × 75 mm). At the center of each face, an area approximately 1 in. (25 mm) in diameter shall be marked with a 950°F (510°C) temperature-indicating crayon or paint. The marked area shall be heated with a blowtorch, a Bunsen burner, or similar device to a temperature between 950°F (510°C) and 975°F (524°C). The specimen shall then be immediately quenched in cold water, which produces a network of fine cracks on each face.

The block shall then be dried by heating to approximately 300°F (149°C). After cooling, the block shall be cut in half. One-half of the specimen shall be designated block "A" and the other block "B" for identification in subsequent processing. Figure III-630 illustrates the comparator blocks "A" and "B." As an alternate to cutting the block in half to make blocks "A" and "B," separate blocks 2 in. × 3 in. (50 mm × 75 mm) can be made using the heating and quenching technique as described above. Two comparator blocks with closely matched crack patterns may be used. The blocks shall be marked "A" and "B."

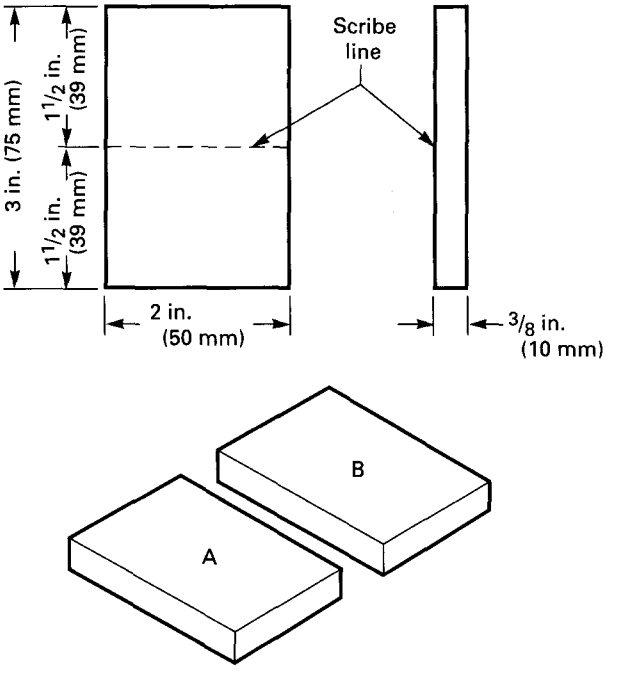


FIG. III-630 LIQUID PENETRANT COMPARATOR
(NOTE: Dimensions given are for guidance only and are not critical.)

III-640 REQUIREMENTS

III-641 Comparator Application

III-641.1 Temperature Less Than 50°F (10°C). If it is desired to qualify a liquid penetrant examination procedure at a temperature of less than 50°F (10°C), the proposed procedure shall be applied to block "B" after the block and all materials have been cooled and held at the proposed examination temperature until the comparison is completed. A standard procedure which has previously been demonstrated as suitable for use shall be applied to block "A" in the 50°F to 125°F (10°C to 52°C) temperature range. The indications of cracks shall be compared between blocks "A" and "B." If the indications obtained under the proposed conditions on block "B" are essentially the same as obtained on block "A" during examination at 50°F to 125°F (10°C to 52°C), the proposed procedure shall be considered qualified for use. A procedure qualified at a temperature lower than 50°F (10°C) shall be qualified from that temperature to 50°F (10°C).

III-641.2 Temperature Greater Than 125°F (52°C). If the proposed temperature for the examination is above 125°F (52°C), block "B" shall be held at this temperature throughout the examination. The indications of cracks shall be compared as described in III-641.1 while block "B" is at the proposed temperature and block "A" is at the 50°F to 125°F (10°C to 52°C) temperature range.

To qualify a procedure for temperatures above 125°F (52°C), the upper and lower temperature limits shall be established and the procedure qualified at these temperatures. [As an example, to qualify a procedure for the temperature range 126°F (52°C) to 200°F (93°C), the capability of a penetrant to reveal indications on the comparator shall be demonstrated at both temperatures.]

III-641.3 Alternate Techniques for Color Contrast Penetrants. As an alternate to the requirements of III-641.1 and III-641.2, when using color contrast penetrants, it is permissible to use a single comparator block for the standard and nonstandard temperatures and to make the comparison by photography.

(a) When the single comparator block and photographic technique is used, the processing details (as applicable) described in III-641.1 and III-641.2 apply. The block shall be thoroughly cleaned between the two processing steps. Photographs shall be taken after processing at the nonstandard temperature and then after processing at the standard temperature. The indication of cracks shall be compared between the two photographs. The same criteria for qualification as III-641.1 shall apply.

(b) Identical photographic techniques shall be used to make the comparison photographs.

ARTICLE 7
MAGNETIC PARTICLE EXAMINATION

T-710 SCOPE

When specified by the referencing Code Section, the magnetic particle examination techniques described in this Article shall be used. In general, this Article is in conformance with SE-709, Standard Guide for Magnetic Particle Examination. This document provides details to be considered in the procedures used.

When this Article is specified by a referencing Code Section, the magnetic particle method described in this Article shall be used together with Article 1, General Requirements. Definition of terms used in this Article are in Mandatory Appendix II.

T-720 GENERAL

The magnetic particle examination method may be applied to detect cracks and other discontinuities on or near the surfaces of ferromagnetic materials. The sensitivity is greatest for surface discontinuities and diminishes rapidly with increasing depth of subsurface discontinuities below the surface. Typical types of discontinuities that can be detected by this method are cracks, laps, seams, cold shuts, and laminations.

In principle, this method involves magnetizing an area to be examined, and applying ferromagnetic particles (the examination's medium) to the surface. The particles will form patterns on the surface where cracks and other discontinuities cause distortions in the normal magnetic field. These patterns are usually characteristic of the type of discontinuity that is detected.

Whichever technique is used to produce the magnetic flux in the part, maximum sensitivity will be to linear discontinuities oriented perpendicular to the lines of flux. For optimum effectiveness in detecting all types of discontinuities, each area is to be examined at least twice, with the lines of flux during one examination approximately perpendicular to the lines of flux during the other.

T-721 Written Procedure Requirements

T-721.1 Requirements. Magnetic particle examination shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-721. The written procedure shall establish a single value, or range of values, for each requirement.

T-721.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-721 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure. A05

T-730 EQUIPMENT

A suitable and appropriate means for producing the necessary magnetic flux in the part shall be employed, using one or more of the techniques listed in and described in T-750.

T-731 Examination Medium

The finely divided ferromagnetic particles used for the examination shall meet the following requirements.

(a) Particle Types. The particles shall be treated to impart color (fluorescent pigments, nonfluorescent pigments, or both) in order to make them highly visible (contrasting) against the background of the surface being examined.

(b) Particles. Dry and wet particles, including wet particle suspension vehicles, and particle concentration shall be in accordance with SE-709.

(c) Temperature Limitations. Particles shall be used within the temperature range limitations set by the manufacturer of the particles. Alternatively, particles may be used outside the particle manufacturer's recommendations providing the procedure is qualified in accordance with Article 1, T-150 at the proposed temperature.

A06 TABLE T-721
REQUIREMENTS OF A MAGNETIC PARTICLE EXAMINATION PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Magnetizing technique	X	...
Magnetizing current type or amperage outside range specified by this Article or as previously qualified	X	...
Surface preparation	X	...
Magnetic particles (fluorescent/visible, color, particle size, wet/dry)	X	...
Method of particle application	X	...
Method of excess particle removal	X	...
Minimum light intensity	X	...
Existing coatings, greater than the thickness demonstrated	X	...
Nonmagnetic surface contrast enhancement, when utilized	X	...
Performance demonstration, when required	X	...
Examination part surface temperature outside of the temperature range recommended by the manufacturer of the particles or as previously qualified	X	...
Shape or size of the examination object	...	X
Equipment of the same type	...	X
Temperature (within those specified by manufacturer or as previously qualified)	...	X
Demagnetizing technique	...	X
Post-examination cleaning technique	...	X
Personnel qualification requirements	...	X

T-740 MISCELLANEOUS REQUIREMENTS

T-741 Surface Conditioning

T-741.1 Preparation

(a) Satisfactory results are usually obtained when the surfaces are in the as-welded, as-rolled, as-cast, or as-forged conditions. However, surface preparation by grinding or machining may be necessary where surface irregularities could mask indications due to discontinuities.

(b) Prior to magnetic particle examination, the surface to be examined and all adjacent areas within at least 1 in. (25 mm) shall be dry and free of all dirt, grease, lint, scale, welding flux and spatter, oil, or other extraneous matter that could interfere with the examination.

(c) Cleaning may be accomplished using detergents, organic solvents, descaling solutions, paint removers, vapor degreasing, sand or grit blasting, or ultrasonic cleaning methods.

(d) If nonmagnetic coatings are left on the part in the area being examined, it shall be demonstrated that indications can be detected through the existing maximum coating thickness applied. When AC yoke technique is used, the demonstration shall be in accordance with Mandatory Appendix I of this Article.

A06 **T-741.2 Nonmagnetic Surface Contrast Enhancement.** Nonmagnetic surface contrasts may be applied by the examiner to uncoated surfaces, only in amounts sufficient to enhance particle contrast. When nonmagnetic surface contrast enhancement is used, it shall be demonstrated that indications can be detected through the enhancement. Thickness measurement of this nonmagnetic surface contrast enhancement is not required.

NOTE: Refer to T-150(a) for guidance for the demonstration required in T-741.1(d) and T-741.2.

T-750 TECHNIQUE

T-751 Techniques

One or more of the following five magnetization techniques shall be used:

(a) prod technique;
(b) longitudinal magnetization technique;
(c) circular magnetization technique;
(d) yoke technique;
(e) multidirectional magnetization technique.

T-752 Prod Technique

T-752.1 Magnetizing Procedure. For the prod technique, magnetization is accomplished by portable prod type electrical contacts pressed against the surface in the area to be examined. To avoid arcing, a remote control switch, which may be built into the prod handles, shall be provided to permit the current to be applied after the prods have been properly positioned.

T-752.2 Magnetizing Current. Direct or rectified magnetizing current shall be used. The current shall be 100 (minimum) amp/in. (4 amp/mm) to 125 (maximum) amp/in. (5 amp/mm) of prod spacing for sections $^3/_4$ in. (19 mm) thick or greater. For sections less than $^3/_4$ in. (19 mm) thick, the current shall be 90 amp/in. (3.6 amp/mm) to 110 amp/in. (4.4 amp/mm) of prod spacing.

T-752.3 Prod Spacing. Prod spacing shall not exceed 8 in. (200 mm). Shorter spacing may be used to accommodate the geometric limitations of the area being examined or to increase the sensitivity, but prod spacings of less than 3 in. (75 mm) are usually not practical due to banding of the particles around the prods. The prod tips shall be kept clean and dressed. If the open circuit voltage of the magnetizing current source is greater than 25 V, lead, steel, or aluminum (rather than copper) tipped prods are recommended to avoid copper deposits on the part being examined.

T-753 Longitudinal Magnetization Technique

T-753.1 Magnetizing Procedure. For this technique, magnetization is accomplished by passing current through a multi-turn fixed coil (or cables) that is wrapped around the part or section of the part to be examined. This produces a longitudinal magnetic field parallel to the axis of the coil.

If a fixed, prewound coil is used, the part shall be placed near the side of the coil during inspection. This is of special importance when the coil opening is more than 10 times the cross-sectional area of the part.

T-753.2 Magnetic Field Strength. Direct or rectified current shall be used to magnetize parts examined by this technique. The required field strength shall be calculated based on the length L and the diameter D of the part in accordance with (a) and (b), or as established in (d) and (e), below. Long parts shall be examined in sections not to exceed 18 in. (450 mm), and 18 in. (450 mm) shall be used for the part L in calculating the required field strength. For noncylindrical parts, D shall be the maximum cross-sectional diagonal.

(a) Parts With L/D Ratios Equal to or Greater Than 4. The magnetizing current shall be within ±10% of the ampere-turns' value determined as follows:

$$\text{Ampere-turns} = \frac{35{,}000}{(L/D) + 2}$$

For example, a part 10 in. (250 mm) long × 2 in. (50 mm) diameter has an L/D ratio of 5. Therefore,

$$\frac{35{,}000}{(L/D + 2)} = 5000 \text{ ampere-turns}$$

(b) Parts With L/D Ratios Less Than 4 but Not Less Than 2. The magnetizing ampere-turns shall be within ±10% of the ampere-turns' value determined as follows:

$$\text{Ampere-turns} = \frac{45{,}000}{L/D}$$

(c) Parts With L/D Ratios Less Than 2. Coil magnetization technique cannot be used.

(d) If the area to be magnetized extends beyond 9 in. (225 mm) on either side of the coil's center, field adequacy shall be demonstrated using a magnetic field indicator or artificial flaw shims per T-764.

(e) For large parts due to size and shape, the magnetizing current shall be 1200 ampere-turns to 4500 ampere-turns. The field adequacy shall be demonstrated using artificial flaw shims or a pie-shaped magnetic field indicator in accordance with T-764. A Hall-Effect probe gaussmeter shall not be used with encircling coil magnetization techniques.

T-753.3 Magnetizing Current. The current required to obtain the necessary magnetizing field strength shall be determined by dividing the ampere-turns obtained in steps (a) or (b) above by the number of turns in the coil as follows:

$$\text{Amperes (meter reading)} = \frac{\text{ampere-turns}}{\text{turns}}$$

For example, if a 5-turn coil is used and the ampere-turns required are 5000, use

$$\frac{5000}{5} = 1000 \text{ amperes } (\pm 10\%)$$

T-754 Circular Magnetization Technique

T-754.1 Direct Contact Technique

(a) Magnetizing Procedure. For this technique, magnetization is accomplished by passing current through the part to be examined. This produces a *circular* magnetic field that is approximately perpendicular to the direction of current flow in the part.

(b) Magnetizing Current. Direct or rectified (half-wave rectified or full-wave rectified) magnetizing current shall be used.

(1) The current shall be 300 amp/in. (12 A/mm) to 800 amp/in. (31 A/mm) of outer diameter.

(2) Parts with geometric shapes other than round with the greatest cross-sectional diagonal in a plane at right angles to the current flow shall determine the inches to be used in (b)(1) above.

(3) If the current levels required for (b)(1) cannot be obtained, the maximum current obtainable shall be

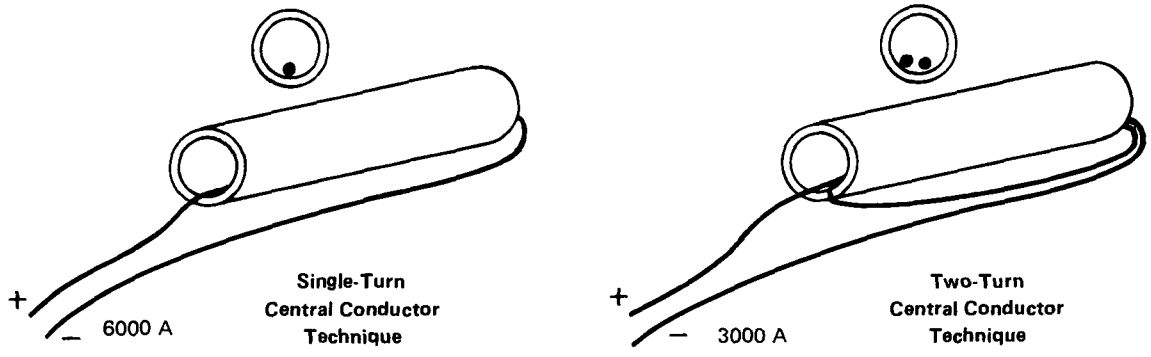


FIG. T-754.2.1 SINGLE-PASS AND TWO-PASS CENTRAL CONDUCTOR TECHNIQUE

used and the field adequacy shall be demonstrated in accordance with T-764.

T-754.2 Central Conductor Technique

(a) Magnetizing Procedure. For this technique, a central conductor is used to examine the internal surfaces of cylindrically or ring-shaped parts. The central conductor technique may also be used for examining the outside surfaces of these shapes. Where large diameter cylinders are to be examined, the conductor shall be positioned close to the internal surface of the cylinder. When the conductor is not centered, the circumference of the cylinder shall be examined in increments. Field strength measurements in accordance with T-764 shall be used, to determine the extent of the arc that may be examined for each conductor position or the rules in (c) below may be followed. Bars or cables, passed through the bore of a cylinder, may be used to induce circular magnetization.

(b) Magnetizing Current. The field strength required shall be equal to that determined in T-754.1(b) for a single-turn central conductor. The magnetic field will increase in proportion to the number of times the central conductor cable passes through a hollow part. For example, if 6000 amperes are required to examine a part using a single pass central conductor, then 3000 amperes are required when 2 passes of the through-cable are used, and 1200 amperes are required if 5 passes are used (see Fig. T-754.2.1). When the central conductor technique is used, magnetic field adequacy shall be verified using a magnetic particle field indicator in accordance with T-764.

(c) Offset Central Conductor. When the conductor passing through the inside of the part is placed against an inside wall of the part, the current levels, as given in T-754.1(b)(1) shall apply, except that the diameter used for current calculations shall be the sum of the diameter of the central conductor and twice the wall thickness. The distance along the part circumference (exterior) that is effectively magnetized shall be taken as four times the diameter of the central conductor, as illustrated in Fig. T-754.2.2. The entire circumference shall be inspected by rotating the part on the conductor, allowing for approximately a 10% magnetic field overlap.

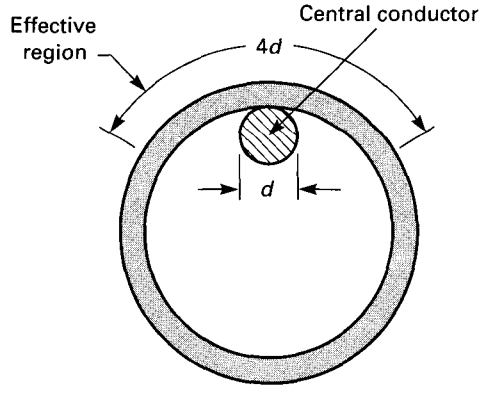


FIG. T-754.2.2 THE EFFECTIVE REGION OF EXAMINATION WHEN USING AN OFFSET CENTRAL CONDUCTOR

T-755 Yoke Technique

T-755.1 Application. This method shall only be applied to detect discontinuities that are open to the surface of the part.

T-755.2 Magnetizing Procedure. For this technique, alternating or direct current electromagnetic yokes, or permanent magnet yokes, shall be used. A06

T-756 Multidirectional Magnetization Technique

T-756.1 Magnetizing Procedure. For this technique, magnetization is accomplished by high amperage power packs operating as many as three circuits that are energized one at a time in rapid succession. The effect of these

rapidly alternating magnetizing currents is to produce an overall magnetization of the part in multiple directions. Circular or longitudinal magnetic fields may be generated in any combination using the various techniques described in T-753 and T-754.

T-756.2 Magnetic Field Strength. Only three phase, full-wave rectified current shall be used to magnetize the part. The initial magnetizing current requirements for each circuit shall be established using the previously described guidelines (see T-753 and T-754). The adequacy of the magnetic field shall be demonstrated using artificial flaw shims or a pie-shaped magnetic particle field indicator in accordance with T-764. A Hall-Effect probe gaussmeter shall not be used to measure field adequacy for the multidirectional magnetization technique. An adequate field shall be obtained in at least two nearly perpendicular directions, and the field intensities shall be balanced so that a strong field in one direction does not overwhelm the field in the other direction. For areas where adequate field strengths cannot be demonstrated, additional magnetic particle techniques shall be used to obtain the required two-directional coverage.

T-760 CALIBRATION

T-761 Frequency of Calibration

T-761.1 Magnetizing Equipment

(a) Frequency. Magnetizing equipment with an ammeter shall be calibrated at least once a year, or whenever the equipment has been subjected to major electric repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

(b) Procedure. The accuracy of the unit's meter shall be verified annually by equipment traceable to a national standard. Comparative readings shall be taken for at least three different current output levels encompassing the usable range.

(c) Tolerance. The unit's meter reading shall not deviate by more than ±10% of full scale, relative to the actual current value as shown by the test meter.

T-761.2 Light Meters. Light meters, both visible and fluorescent (black) light meters, shall be calibrated at least once a year or whenever the meter has been repaired. If meters have not been in use for one year or more, calibration shall be done before being used.

T-762 Lifting Power of Yokes

(a) Prior to use, the magnetizing power of electromagnetic yokes shall have been checked within the past year. The magnetizing power of permanent magnetic yokes shall be checked daily prior to use. The magnetizing power of all yokes shall be checked whenever the yoke has been damaged or repaired.

(b) Each alternating current electromagnetic yoke shall have a lifting power of at least 10 lb (4.5 kg) at the maximum pole spacing that will be used.

(c) Each direct current or permanent magnetic yoke shall have a lifting power of at least 40 lb (18 kg) at the maximum pole spacing that will be used.

(d) Each weight shall be weighed with a scale from a reputable manufacturer and stenciled with the applicable nominal weight prior to first use. A weight need only be verified again if damaged in a manner that could have caused potential loss of material.

T-763 Gaussmeters

Hall-Effect probe gaussmeters used to verify magnetizing field strength in accordance with T-754 shall be calibrated at least once a year or whenever the equipment has been subjected to a major repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to first use.

T-764 Magnetic Field Adequacy and Direction

T-764.1 Magnetic Field Adequacy. The applied magnetic field shall have sufficient strength to produce satisfactory indications, but shall not be so strong that it causes masking of relevant indications by nonrelevant accumulations of magnetic particles. Factors that influence the required field strength include the size, shape, and material permeability of the part; the technique of magnetization; coatings; the method of particle application; and the type and location of discontinuities to be detected. When it is necessary to verify the adequacy of magnetic field strength, it shall be verified by using one or more of the following three methods.

T-764.1.1 Pie-Shaped Magnetic Particle Field Indicator. The indicator, shown in Fig. T-764.1.1, shall be positioned on the surface to be examined, such that the copper-plated side is away from the inspected surface. A suitable field strength is indicated when a clearly defined line (or lines) of magnetic particles form(s) across the copper face of the indicator when the magnetic particles are applied simultaneously with the magnetizing force. When a clearly defined line of particles is not formed, the magnetizing technique shall be changed as needed. Pie-type indicators are best used with dry particle procedures.

T-764.1.2 Artificial Flaw Shims. The shim, shown in Fig. T-764.1.2, shall be attached to the surface to be examined, such that the artificial flaw side of the shim

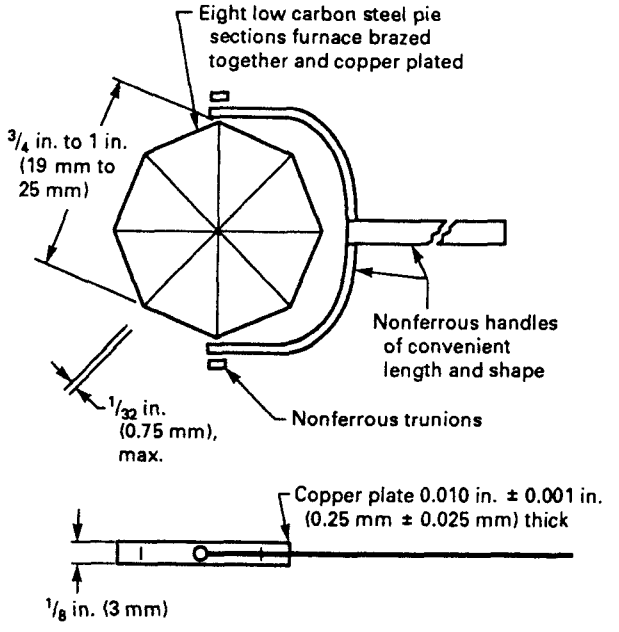
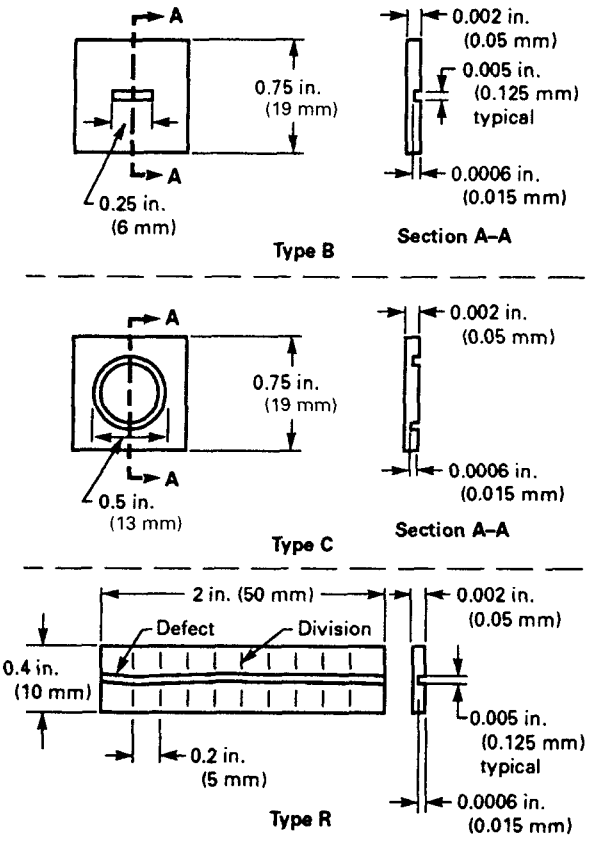


FIG. T-764.1.1 PIE-SHAPED MAGNETIC PARTICLE FIELD INDICATOR



GENERAL NOTE: Above are examples of artificial flaw shims used in magnetic particle inspection system verification (not drawn to scale). The shims are made of low carbon steel (1005 steel foil). The artificial flaw is etched or machined on one side of the foil to a depth of 30% of the foil thickness.

FIG. T-764.1.2 ARTIFICIAL FLAW SHIMS

is toward the inspected surface. A suitable field strength is indicated when a clearly defined line (or lines) of magnetic particles, representing the 30% depth flaw, appear(s) on the shim face when magnetic particles are applied simultaneously with the magnetizing force. When a clearly defined line of particles is not formed, the magnetizing technique shall be changed as needed. Shim-type indicators are best used with wet particle procedures.

T-764.1.3 Hall-Effect Tangential-Field Probe. A gaussmeter and Hall-Effect tangential-field probe shall be used for measuring the peak value of a tangential field. The probe shall be positioned on the surface to be examined, such that the maximum field strength is determined. A suitable field strength is indicated when the measured field is within the range of 30 G to 60 G (2.4 kAm^{-1} to 4.8 kAm^{-1}) while the magnetizing force is being applied. See Article 7, Nonmandatory Appendix A.

T-764.2 Magnetic Field Direction. The direction of magnetization shall be determined by particle indications obtained using an indicator or shims as shown in Fig. T-764.1.1 or Fig. T-764.1.2. When a clearly defined line of particles is not formed in the desired direction, the magnetizing technique shall be changed as needed.

T-764.2.1 For multidirectional magnetization techniques, the orientation of the lines of flux shall be in at least two nearly perpendicular directions. When clearly defined lines of particles are not formed in at least two nearly perpendicular directions, the magnetizing technique shall be changed as needed.

T-764.3 Determination of the adequacy and direction of magnetizing fields using magnetic field indicators or artificial flaw shims are only permitted when specifically referenced by the magnetizing techniques in T-753.2(d), T-753.2(e), T-754.1(b)(3), T-754.2(a), T-754.2(b), and T-756.2.

T-765 Wet Particle Concentration and Contamination

Wet Horizontal Units shall have the bath concentration and bath contamination determined by measuring its settling volume. This is accomplished through the use of an ASTM Test Method D 96 pear-shaped centrifuge tube with a 1-mL stem (0.05-mL divisions) for fluorescent particle suspensions or a 1.5-mL stem (0.1-mL divisions)

for nonfluorescent suspensions. Before sampling, the suspension should be run through the recirculating system for at least 30 min to ensure thorough mixing of all particles which could have settled on the sump screen and along the sides or bottom of the tank.

T-765.1 Concentration. Take a 100-mL portion of the suspension from the hose or nozzle, demagnetize and allow it to settle for approximately 60 min with petroleum distillate suspensions or 30 min with water-based suspensions before reading. The volume settling out at the bottom of the tube is indicative of the particle concentration in the bath.

T-765.2 Settling Volumes. For fluorescent particles, the required settling volume is from 0.1 to 0.4 mL in a 100-mL bath sample and from 1.2 to 2.4 mL per 100 mL of vehicle for nonfluorescent particles unless otherwise specified by the particle manufacturer. Concentration checks shall be made at least every eight hours.

T-765.3 Contamination. Both fluorescent and nonfluorescent suspensions shall be checked periodically for contaminants such as dirt, scale, oil, lint, loose fluorescent pigment, water (in the case of oil suspensions), and particle agglomerates which can adversely affect the performance of the magnetic particle examination process. The test for contamination shall be performed at least once per week.

(a) Carrier Contamination. For fluorescent baths, the liquid directly above the precipitate should be examined with black light. The liquid will have a little fluorescence. Its color can be compared with a freshly made-up sample using the same materials or with an unused sample from the original bath that was retained for this purpose. If the "used" sample is noticeably more fluorescent than the comparison standard, the bath shall be replaced.

(b) Particle Contamination. The graduated portion of the tube shall be examined under black light if the bath is fluorescent and under visible light (for both fluorescent and nonfluorescent particles) for striations or bands, differences in color or appearance. Bands or striations may indicate contamination. If the total volume of the contaminates, including bands or striations exceeds 30% of the volume magnetic particles, or if the liquid is noticeably fluorescent, the bath shall be replaced.

T-766 System Performance of Horizontal Units

The Ketos (Betz) ring specimen (see Fig. T-766.1) shall be used in evaluating and comparing the overall performance and sensitivity of both dry and wet, fluorescent and nonfluorescent magnetic particle techniques using a central conductor magnetization technique.

(a) Ketos (Betz) Test Ring Material. The tool steel (Ketos) ring should be machined from AISI 01 material in accordance with Fig. T-766.1. Either the machined ring or the steel blank should be annealed at 1650°F (900°C), cooled 50°F (28°C) per hour to 1000°F (540°C) and then air cooled to ambient temperature to give comparable results using similar rings that have had the same treatment. Material and heat treatment are important variables. Experience indicates controlling the softness of the ring by hardness (90 to 95 HRB) alone is insufficient.

(b) Using the Test Ring. The test ring (see Fig. T-766.1), is circularly magnetized with full-wave rectified AC passing through a central conductor with a 1 to $1\frac{1}{4}$ in. (25 to 32 mm) diameter hole located in the ring center. The conductor should have a length greater than 16 in. (400 mm). The currents used shall be 1400, 2500, and 3400 amps. The minimum number of holes shown shall be three, five, and six, respectively. The ring edge should be examined with either black light or visible light, depending on the type of particles involved. This test shall be run at the three amperages if the unit will be used at these or higher amperages. The amperage values stated shall not be exceeded in the test. If the test does not reveal the required number of holes, the equipment shall be taken out of service and the cause of the loss of sensitivity determined and corrected. This test shall be run at least once per week.

T-770 EXAMINATION

T-771 Preliminary Examination

Before the magnetic particle examination is conducted, a check of the examination surface shall be conducted to locate any discontinuity surface openings which may not attract and hold magnetic particles because of their width.

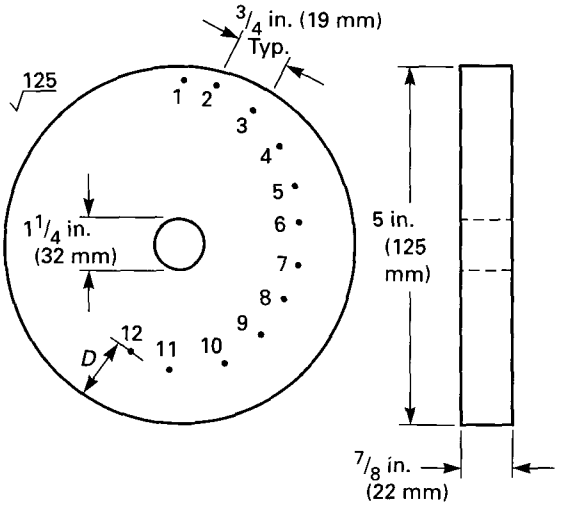
T-772 Direction of Magnetization

At least two separate examinations shall be performed on each area. During the second examination, the lines of magnetic flux shall be approximately perpendicular to those used during the first examination. A different technique for magnetization may be used for the second examination.

T-773 Method of Examination

The ferromagnetic particles used in an examination medium can be either wet or dry, and may be either fluorescent or nonfluorescent. Examination(s) shall be done by the continuous method.

(a) Dry Particles. The magnetizing current shall remain on while the examination medium is being applied



Hole	1	2	3	4	5	6	7	8	9	10	11	12
Diameter [Note (1)]	0.07 (1.8 mm)	0.07 (1.8 mm)	0.07 (1.8 mm)	0.07 (1.8 mm)	0.07 (1.8 mm)	0.07 (1.8 mm)	0.07 (1.8 mm)	0.07 (1.8 mm)	0.07 (1.8 mm)	0.07 (1.8 mm)	0.07 (1.8 mm)	0.07 (1.8 mm)
"D" [Note (2)]	0.07 (1.8 mm)	0.14 (3.6 mm)	0.21 (5.3 mm)	0.28 (7.1 mm)	0.35 (9.0 mm)	0.42 (10.8 mm)	0.49 (12.6 mm)	0.56 (14.4 mm)	0.63 (16.2 mm)	0.70 (18.0 mm)	0.77 (19.8 mm)	0.84 (21.6 mm

NOTES:

(1) All hole diameters are ±0.005 in. (±0.1 mm.) Hole numbers 8 through 12 are optional.

(2) Tolerance on the *D* distance is ±0.005 in. (±0.1 mm).

GENERAL NOTES:

(a) All dimensions are ±0.03 in. (±0.8 mm) or as noted in Notes (1) and (2).

(b) All dimensions are in inches, except as noted.

(c) Material is ANSI O1 tool steel from annealed round stock.

(d) The ring may be heat treated as follows: Heat to 1400°F to 1500°F (760°C to 790°C). Hold at this temperature for one hour. Cool to a minimum rate of 40°F/h (22°C/h) to below 1000°F (540°C). Furnace or air cool to room temperature. Finish the ring to RMS 25 and protect from corrosion.

FIG. T-766.1 KETOS (BETZ) TEST RING

and while any excess of the examination medium is removed.

(b) Wet Particles. The magnetizing current shall be turned on after the particles have been applied. Flow of particles shall stop with the application of current. Wet particles applied from aerosol spray cans may be applied before and/or after magnetizing current is applied. Wet particles may be applied during the application of magnetizing current if they are not applied directly to the examination area and are allowed to flow over the examination area or are applied directly to the examination area with low velocities insufficient to remove accumulated particles.

T-774 Examination Coverage

All examinations shall be conducted with sufficient field overlap to ensure 100% coverage at the required sensitivity (T-764).

T-775 Rectified Current

(a) Whenever direct current is required rectified current may be used. The rectified current for magnetization shall be either three-phase (full-wave rectified) current, or single phase (half-wave rectified) current.

(b) The amperage required with three-phase, full-wave rectified current shall be verified by measuring the average current.

(c) The amperage required with single-phase (half-wave rectified) current shall be verified by measuring the average current output during the conducting half cycle only.

(d) When measuring half-wave rectified current with a direct current test meter, readings shall be multiplied by two.

T-776 Excess Particle Removal

Accumulations of excess dry particles in examinations shall be removed with a light air stream from a bulb or syringe or other source of low pressure dry air. The examination current or power shall be maintained while removing the excess particles.

T-777 Interpretation

The interpretation shall identify if an indication as false, nonrelevant, or relevant. False and nonrelevant indications shall be proven as false or nonrelevant. Interpretation shall be carried out to identify the locations of indications and the character of the indication.

T-777.1 Visible (Color Contrast) Magnetic Particles. Surface discontinuities are indicated by accumulations of magnetic particles which should contrast with the examination surface. The color of the magnetic particles shall be sufficiently different than the color of the examination surface. A minimum light intensity of 100 fc (1000 Lx) is required on the surface to be examined to ensure adequate sensitivity during the examination and evaluation of indications. The light source, technique used, and light level verification is required to be demonstrated one time, documented, and maintained on file.

A05 **T-777.2 Fluorescent Magnetic Particles.** With fluorescent magnetic particles, the process is essentially the same as in T-777.1, with the exception that the examination is performed using an ultraviolet light, called *black light.* The examination shall be performed as follows:

(a) It shall be performed in a darkened area.

(b) Examiners shall be in a darkened area for at least 5 min prior to performing examinations to enable their eyes to adapt to dark viewing. Glasses or lenses worn by examiners shall not be photosensitive.

(c) Black lights shall achieve a minimum of 1000 $\mu W/cm^2$ on the surface of the part being examined throughout the examination.

(d) Reflectors and filters should be checked and, if necessary, cleaned prior to use. Cracked or broken filters shall be replaced immediately.

(e) The black light intensity shall be measured with a black light meter prior to use, whenever the light's power source is interrupted or changed, and at the completion of the examination or series of examinations.

T-778 Demagnetization

When residual magnetism in the part could interfere with subsequent processing or usage, the part shall be demagnetized any time after completion of the examination.

T-779 Post-Examination Cleaning 04

When post-examination cleaning is required, it should be conducted as soon as practical using a process that does not adversely affect the part.

T-780 EVALUATION

(a) All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

(b) Discontinuities on or near the surface are indicated by retention of the examination medium. However, localized surface irregularities due to machining marks or other surface conditions may produce false indications.

(c) Broad areas of particle accumulation, which might mask indications from discontinuities, are prohibited, and such areas shall be cleaned and reexamined.

T-790 DOCUMENTATION

T-791 Multidirectional Magnetization Technique Sketch

A technique sketch shall be prepared for each different geometry examined, showing the part geometry, cable arrangement and connections, magnetizing current for each circuit, and the areas of examination where adequate field strengths are obtained. Parts with repetitive geometries, but different dimensions, may be examined using a single sketch provided that the magnetic field strength is adequate when demonstrated in accordance with T-755.2.

T-792 Recording of Indications

T-792.1 Nonrejectable Indications. Nonrejectable indications shall be recorded as specified by the referencing Code Section.

T-792.2 Rejectable Indications. Rejectable indications shall be recorded. As a minimum, the type of indications (linear or rounded), location and extent (length or diameter or aligned) shall be recorded.

T-793 Examination Records

For each examination, the following information shall be recorded:

(a) procedure identification and revision;

(b) magnetic particle equipment and type of current;

(c) magnetic particles (visible or fluorescent, wet or dry);

(d) examination personnel identity and if required by referencing Code Section, qualification level;

(e) map or record of indications per T-792;

(f) material and thickness;

(g) lighting equipment; and

(h) date of examination. A06

T-794 Performance Demonstration

Performance demonstration, when required by the referencing Code Section, shall be documented.

ARTICLE 7
MANDATORY APPENDICES

APPENDIX I — MAGNETIC PARTICLE EXAMINATION USING THE AC YOKE TECHNIQUE ON FERRITIC MATERIALS COATED WITH NONMAGNETIC COATINGS

I-710 SCOPE

This Appendix provides the Magnetic Particle examination methodology and equipment requirements applicable for performing Magnetic Particle examination on ferritic materials with nonmagnetic coatings.

I-720 GENERAL

Requirements of Article 7 apply unless modified by this Appendix.

I-721 Written Procedure Requirements

I-721.1 Requirements. Magnetic Particle examination shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements listed in Tables T-721 and I-721. The written procedure shall establish a single value, or range of values, for each requirement.

I-721.2 Procedure Qualification/Technique Validation. When procedure qualification is specified, a change of a requirement in Table T-721 or I-721 identified as an essential variable from the specfied value, or range of values, shall require requalification of the written procedure and validation of the technique. A change of a requirement identified as an nonessential variable from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

I-722 Personnel Qualification

Personnel qualification requirements shall be in accordance with the referencing Code Section.

I-723 Procedure/Technique Demonstration

The procedure/technique shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

I-730 EQUIPMENT

I-730.1 The magnetizing equipment shall be in accordance with Article 7.

I-730.2 When the dry powder technique is used, a powder blower shall be utilized for powder application. Hand squeezed particle applicators shall not be used when the dry powder technique is utilized.

I-730.3 Magnetic particles shall contrast with the component background.

I-730.4 Nonconductive materials such as plastic shim stock may be used to simulate nonconductive nonmagnetic coatings for procedure and personnel qualification.

I-740 MISCELLANEOUS REQUIREMENTS

I-741 Coating Thickness Measurement

The procedure demonstration and performance of examinations shall be preceded by measurement of the coating thickness in the areas to be examined. If the coating is nonconductive, an eddy current technique or magnetic technique may be used to measure the coating thickness. The magnetic technique shall be in accordance with ASTM D 1186, Standard Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base. When coatings are conductive and nonmagnetic, a coating thickness technique shall be used in accordance with D 1186. Coating measurement equipment shall be used in accordance with the equipment manufacturer's instructions. Coating thickness measurements shall be taken at the intersections of a 2 in. (50 mm) maximum grid pattern over the area of examination and at least one-half the maximum yoke leg separation beyond the examination

TABLE I-721
REQUIREMENTS OF AC YOKE TECHNIQUE ON COATED FERRITIC COMPONENT

Requirement	Essential Variable	Nonessential Variable
Identification of surface configurations to be examined, including coating materials, maximum qualified coating thickness, and product forms (e.g., base material or welded surface)	X	
Surface condition requirements and preparation methods	X	
Manufacturer and model of AC yoke	X	
Manufacturer and type of magnetic particles	X	
Minimum and maximum pole separation	X	
Identification of the steps in performing the examination	X	
Minimum lighting intensity and AC yoke lifting power requirements (as measured in accordance with Technique Qualification (I-721.2)	X	
Methods of identifying flaw indications and discriminating between flaw indications and false or nonrelevant indications (e.g., magnetic writing or particles held by surface irregularities)	X	
Instructions for identification and confirmation of suspected flaw indications	X	
Method of measuring coating thickeness		X
Recording criteria		X
Personnel qualification requirements unique to this technique		X
Reference to the procedure qualification records		X

area. The thickness shall be the mean of three separate readings within $\frac{1}{4}$ in. (6 mm) of each intersection.

I-750 TECHNIQUE

I-751 Technique Qualification

(a) A qualification specimen is required. The specimen shall be of similar geometry or weld profile and contain at least one surface crack no longer than the maximum flaw size allowed in the applicable acceptance criteria. The material used for the specimen shall be the same specification and heat treatment as the coated ferromagnetic material to be examined. As an alternative to the material requirement, other materials and heat treatments may be qualified provided:

(1) The measured yoke maximum lifting force on the material to be examined is equal to or greater than the maximum lifting force on the qualification specimen material. Both values shall be determined with the same or comparable equipment and shall be documented as required in paragraph (c).

(2) All the requirements of paragraphs *(b)* through *(g)* are met for the alternate material.

(b) Examine the uncoated specimen in the most unfavorable orientation expected during the performance of the production examination.

(c) Document the measured yoke maximum lifting power, illumination levels, and the results.

(d) Measure the maximum coating thickness on the item to be examined in accordance with the requirements of I-741.

(e) Coat the specimen with the same type of coating, conductive or nonconductive, to the maximum thickness measured on the production item to be examined. Alternately, nonconductive shim stock may be used to simulate nonconductive coatings.

(f) Examine the coated specimen in the most unfavorable orientation expected during the performance of the production examination. Document the measured yoke maximum lifting power, illumination level, and examination results.

(g) Compare the length of the indication resulting from the longest flaw no longer than the maximum flaw size allowed by the applicable acceptance criteria, before and after coating. The coating thickness is qualified when the length of the indication on the coated surface is at least 50% of the length of the corresponding indication prior to coating.

(h) Requalification of the procedure is required for a decrease in either the AC yoke lifting power or the illumination level, or for an increase in the coating thickness.

I-760 CALIBRATION

I-761 Yoke Maximum Lifting Force

The maximum lifting force of the AC yoke shall be determined at the actual leg separation to be used in the examination. This may be accomplished by holding the yoke with a 10 lb (4.5 kg) ferromagnetic weight between the legs of the yoke and adding additional weights, calibrated on a postage or other scale, until the ferromagnetic

weight is released. The lifting power of the yoke shall be the combined weight of the ferromagnetic material and the added weights, before the ferromagnetic weight was released. Other methods may be used such as a load cell.

I-762 Light Intensity Measurement

The black light or white light intensity (as appropriate) on the surface of the component shall be no less than that used in the qualification test. An appropriate calibrated black light and/or white light meter shall be used for the tests. Minimum white light or black light intensities shall meet the requirements of T-777.1 or T-777.2 as applicable.

I-762.1 White Light. The white light intensity shall be measured at the inspection surface. The white light intensity for the examination shall be no less than what was used in the qualification.

I-762.2 Black Light. The black light intensity shall be measured at the distance from the black light in the procedure qualification and at the same distance on the examination specimen. The black light intensity shall be no less than that used to qualify the procedure. In addition, the maximum white light intensity shall be measured as background light on the inspection surface. The background white light for the examination shall be no greater than what was used in the qualification.

I-770 EXAMINATION

(a) Surfaces to be examined, and all adjacent areas within at least 1 in. (25 mm), shall be free of all dirt, grease, lint, scale, welding flux and spatter, oil, and loose, blistered, flaking, or peeling coating.

(b) Examine the coated item in accordance with the qualified procedure.

I-780 EVALUATION

If an indication greater than 50% of the maximum allowable flaw size is detected, the coating in the area of the indication shall be removed and the examination repeated.

I-790 DOCUMENTATION

I-791 Examination Record

For each examination, the information required in the records section of T-793 and the following information shall be recorded:

(a) identification of the procedure/technique

(b) identification of the personnel performing and witnessing the qualification

(c) description and drawings or sketches of the qualification specimen, including coating thickness measurements and flaw dimensions

(d) equipment and materials used

(e) illumination level and yoke lifting power

(f) qualification results, including maximum coating thickness and flaws detected.

I-792 Performance Demonstration

Performance demonstration, when required by the referencing Code Section, shall be documented.

APPENDIX II — GLOSSARY OF TERMS FOR MAGNETIC PARTICLE EXAMINATION

II-710 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms which appear in Article 7, Magnetic Particle Examination.

II-720 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 7 provides the definitions of terms listed in II-730(a).

(c) For general terms, such as *Indication, Flaw, Discontinuity, Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph II-730(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

II-730 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: ampere turns, black light, central conductor, circular magnetization, demagnetization, dry powder, full-wave direct current, half-wave current, longitudinal magnetization, magnetic field, magnetic field strength, magnetic particle examination, magnetic particle field indicator, magnetic particles, multidirectional magnetization, permanent magnet, prods, sensitivity, suspension, yoke.

(b) The following Code terms are used in conjunction with this Article:

black light intensity — a quantitative expression of ultraviolet irradiance

magnetic flux — the concept that the magnetic field is flowing along the lines of force suggests that these lines are therefore "flux" lines, and they are called magnetic flux. The strength of the field is defined by the number of flux lines crossing a unit area taken at right angles to the direction of the lines.

rectified magnetic current — by means of a device called a rectifier, which permits current to flow in one direction only, alternating current can be converted to unidirectional current. This differs from direct current in that the current value varies from a steady level. This variation may be extreme, as in the case of the half-wave rectified single phase AC, or slight, as in the case of three-phase rectified AC.

half-wave rectified current AC — when a single-phase alternating current is rectified in the simplest manner, the reverse of the cycle is blocked out entirely. The result is a pulsating unidirectional current with intervals when no current at all is flowing. This is often referred to as "half-wave" or pulsating direct current.

full-wave rectified current — when the reverse half of the cycle is turned around to flow in the same direction as the forward half. The result is full-wave rectified current. Three-phase alternating current when full-wave rectified is unidirectional with very little pulsation; only a ripple of varying voltage distinguishes it from straight DC single-phase.

ARTICLE 7, APPENDIX III REDESIGNATED AS ARTICLE 16 A05

119–121

ARTICLE 7
NONMANDATORY APPENDIX

APPENDIX A — MEASUREMENT OF TANGENTIAL FIELD STRENGTH WITH GAUSSMETERS

A-710 SCOPE

This Nonmandatory Appendix is used for the purpose of establishing procedures and equipment specifications for measuring the tangential applied magnetic field strength.

A-720 GENERAL REQUIREMENTS

Personnel qualification requirements shall be in accordance with Article 1.

Gaussmeters and related equipment shall be calibrated in accordance with T-763 of Article 7.

Definitions: standard terminology for magnetic particle examinations is presented in SE-1316.

A-730 EQUIPMENT

Gaussmeter having the capability of being set to read peak values of field intensity. The frequency response of the gaussmeter shall be at least 0 Hz to 300 Hz.

The Hall-Effect tangential field probe should be no larger than 0.2 in. (5 mm) by 0.2 in. (5 mm) and should have a maximum center location 0.2 in. (5 mm) from the part surface. Probe leads shall be shielded or twisted to prevent reading errors due to voltage induced during the large field changes encountered during magnetic particle examinations.

A-750 PROCEDURE

Care shall be exercised when measuring the tangential applied field strengths specified in T-764.1.3. The plane of the probe must be perpendicular to the surface of the part at the location of measurement to within 5 deg. This may be difficult to accomplish by hand orientation. A jig or fixture may be used to ensure this orientation is achieved and maintained.

The direction and magnitude of the tangential field on the part surface can be determined by placing the Hall-Effect tangential field probe on the part surface in the area of interest. The direction of the field can be determined during the application of the magnetizing field by rotating the tangential field probe while in contact with the part until the highest field reading is obtained on the Gaussmeter. The orientation of the probe, when the highest field is obtained, will indicate the field direction at that point. Gaussmeters cannot be used to determine the adequacy of magnetizing fields for multidirectional and coil magnetization techniques.

Once adequate field strength has been demonstrated with artificial flaw shims, Gaussmeter readings may be used at the location of shim attachment on identical parts or similar configurations to verify field intensity and direction.

A-790 DOCUMENTATION/RECORDS

Documentation should include the following:

(a) equipment model and probe description;

(b) sketch or drawing showing where measurements are made; and

(c) field intensity and direction of measurement.

ARTICLE 8
EDDY CURRENT EXAMINATION OF TUBULAR PRODUCTS

T-810 SCOPE

(a) This Article describes the method to be used when performing eddy current examination of seamless copper, copper alloy, and other nonferromagnetic tubular products. The method conforms substantially with the following Standard listed in Article 26 and reproduced in Subsection B:

SE-243 Electromagnetic (Eddy Current) Testing of Seamless Copper and Copper-Alloy Heat Exchanger and Condenser Tubes.

(b) The requirements of Article 1, General Requirements, also apply when eddy current examination, in accordance with Article 8, is required by a referencing Code Section.

(c) Definitions of terms for eddy current examination appear in Article 1, Appendix I, Subsection B, Article 30 and Mandatory Appendix IV of this Article.

T-820 GENERAL

T-821 Performance

Tubes may be examined at the finish size, after the final anneal or heat treatment, or at the finish size, prior to the final anneal or heat treatment, unless otherwise agreed upon between the supplier and the purchaser. The procedure shall be qualified by demonstrating detection of discontinuities of a size equal to or smaller than those in the reference specimen described in T-833. Indications equal to or greater than those considered reportable by the procedure shall be processed in accordance with T-880.

T-822 Personnel Requirements

The user of this Article shall be responsible for assigning qualified personnel to perform eddy current examinations to the requirements of this Article. Personnel performing examinations shall be qualified as required by the referencing Code Section.

TABLE T-823
REQUIREMENTS OF AN EDDY CURRENT EXAMINATION PROCEDURE

Requirement (As Applicable)	Essential Variable	Non-Essential Variable
Frequency(s)	X	
Mode (Differential/Absolute)	X	
Minimum Fill Factor	X	
Probe Type	X	
Maximum Scanning Speed	X	
Scanning Technique (Automatic/Manual)		X
Material being examined	X	
Material Size/Dimensions	X	
Reference Standard	X	
Equipment Manufacturer/Model	X	
Scanning Equipment/Fixtures		X
Data Recording Equipment	X	
Cabling (Type and Length)	X	
Acquisition Software	X	
Analysis Software	X	

T-823 Procedure

T-823.1 Requirments. Eddy current or other electomagnetic examinations shall be performed in accordance with a written procedure, which shall, as a minimum contain the requirements listed in Table T-823. The written procedure shall establish a single value, or range of values, for each requirement.

T-823.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-823 identified as an essential variable from the specified value, or range of values, shall require requalification of the written procedure. Where a range is specified for an essential variable, the bounding values of the range shall be qualified by demonstration. A change of a requirement identified as a nonessential variable from the specified value, or range of values, does not require requalification of the written procedure. All changes of essential or nonessential variables from the value, or

range of values, specified by the written procedure shall require revision of, or an addendum to, the written procedure.

T-830 EQUIPMENT

Equipment shall consist of electronic apparatus capable of energizing the test coil or probes with alternating currents of suitable frequencies and shall be capable of sensing the changes in the electromagnetic properties of the material. Output produced by this equipment may be processed so as to actuate signaling devices and/or to record examination data.

T-831 Test Coils and Probes

Test coils or probes shall be capable of inducing alternating currents into the material and sensing changes in the electromagnetic characteristics of the material. Test coils should be selected to provide the highest practical fill factor.

T-832 Scanners

Equipment used should be designed to maintain the material concentric within the coil, or to keep the probe centered within the tube and to minimize vibration during scanning. Maximum scanning speeds shall be based on the equipment's data acquisition frequency response or digitizing rate, as applicable.

T-833 Reference Specimen

The reference specimen material shall be processed in the same manner as the product being examined. It shall be the same nominal size and material type (chemical composition and product form) as the tube being examined. Ideally, the specimen should be a part of the material being examined. Unless specified in the referencing Code Section, the reference discontinuities shall be transverse notches or drilled holes as described in Standard Practice SE-243, Section 7, Calibration Standards.

T-840 REQUIREMENTS

T-841 Procedure Requirements

A written procedure, when required according to T-150, shall include at least the following:

(a) frequency

(b) type of coil or probe (e.g., differential coil)

(c) type of material and sizes to which applicable

(d) reference specimen notch or hole size

(e) additional information as necessary to permit retesting

T-850 TECHNIQUE

Specific techniques may include special probe or coil designs, electronics, calibration standards, analytical algorithims and/or display software. Techniques, such as channel mixes, may be used as necessary to suppress signals produced at the ends of tubes. Such techniques shall be in accordance with requirements of the referencing Code Section.

T-860 CALIBRATION

T-861 Performance Verification

Performance of the examination equipment shall be verified by the use of the reference specimen as follows:

(a) As specified in the written procedure:

(1) at the beginning of each production run of a given diameter and thickness of a given material;

(2) at the end of the production run;

(3) at any time that malfunctioning is suspected.

(b) If, during calibration or verification, it is determined that the examination equipment is not functioning properly, all of the product tested since the last calibration or verification shall be re-examined.

(c) When requalification of the written procedure as required in T-823.2.

T-862 Calibration of Equipment

(a) Frequency of Calibration. Eddy current instrumentation shall be calibrated at least once a year, or whenever the equipment has been subjected to a major electronic repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to use.

(b) Documentation. A tag or other form of documentation shall be attached to the eddy current equipment with dates of the calibration and calibration due date.

T-870 EXAMINATION

Tubes are examined by passing through an encircling coil, or past a probe coil with the apparatus set up in accordance with the written procedure. Signals produced by the examination are processed and evaluated. Data may be recorded for post-examination analysis or stored for archival purposes in accordance with the procedure. Outputs resulting from the evaluation may be used to mark and/or separate tubes.

T-880 EVALUATION

Evaluation of examination results for acceptance shall be as specified in the written procedure and in accordance with the referencing Code Section.

T-890 DOCUMENTATION

T-891 Examination Reports

A report of the examination shall contain the following information:

(a) tube material specification, diameter, and wall thickness condition

(b) coil or probe manufacturer, size and type

(c) mode of operation (absolute, differential, etc.)

(d) examination frequency or frequencies

(e) manufacturer, model, and serial number of eddy current equipment

(f) scanning speed

(g) examination procedure number and revision

(h) calibration standard and serial number

(i) identity of examination personnel, and, when required by the referencing Code Section, qualification level

(j) date of inspection

(k) list of acceptable material

(l) date and time of qualification

(m) results of requalification (as applicable)

T-892 Documentation of Performance Demonstration

When required by the referencing Code Section, performance demonstrations shall be documented.

ARTICLE 8
MANDATORY APPENDICES

APPENDIX I — EDDY CURRENT EXAMINATION METHOD FOR INSTALLED NONFERROMAGNETIC HEAT EXCHANGER TUBING

I-800 INTRODUCTION

I-810 SCOPE

This Appendix defines the eddy current (ET) examination method and equipment requirements applicable to installed nonferromagnetic heat exchanger tubing. When specified by the referencing Code Section, the eddy current techniques described in this Appendix shall be used. The methods and techniques described in this Appendix are intended to detect and quantify degradation in the tubing.

I-820 GENERAL REQUIREMENTS

(a) The basis frequency ET examination is required and shall be done in accordance with I-862.

(b) The requirements for test equipment and examination procedures shall be in accordance with I-830.

(c) Calibrations shall be done in accordance with I-860.

(d) Examination shall be done in accordance with I-870.

I-830 EQUIPMENT

Eddy current nondestructive testing equipment capable of operation in the differential mode or the absolute mode, or both, shall be used for this examination. A device for recording data, real time, in a format suitable for evaluation and for archival storage, shall be provided when required by the referencing Code Section.

I-831 Frequency of Calibration

Electronic instrumentation of the eddy current system shall be calibrated at least once a year or whenever the equipment has been overhauled or repaired as a result of malfunction or damage.

I-850 TECHNIQUE

Single frequency or multiple frequency techniques are permitted for this examination. Upon selection of the test frequency(s) and after completion of calibration, the probe shall be inserted into the tube where it is extended or positioned to the region of interest. Resulting eddy current signals at each of the individual frequencies shall be recorded for review, analysis, and final disposition.

I-860 CALIBRATION

I-861 Calibration Tube Standards

The calibration tube standard shall be manufactured from a length of tubing of the same nominal size and material type (chemical composition and product form) as that to be examined in the vessel. The intent of this reference standard is to establish and verify system response. The standard shall contain calibration discontinuities as follows.

(a) A single hole drilled 100% through the wall 0.052 in. (1.3 mm) diameter for $^{3}/_{4}$ in. (19 mm) O.D. tubing and smaller and 0.067 in. (1.7 mm) diameter for larger tubing.

(b) Four flat bottom holes, $^{3}/_{16}$ in. (5 mm) diameter, spaced 90 deg. apart in a single plane around the tube circumference, 20% through the tube wall from the O.D.

(c) A $^{1}/_{16}$ in. (1.5 mm) wide, 360 deg circumferential groove, 10% through from the inner tube surface (optional).

(d) All calibration discontinuities shall be spaced so that they can be identified from each other and from the end of the tube.

(e) Each standard shall be identified by a serial number.

(f) The depth of the calibration discontinuities, at their center, shall be accurate to within ±20% of the specified depth or ±0.003 in. (±0.08 mm), whichever is smaller. All other dimensions shall be accurate to 0.010 in. (0.25 mm).

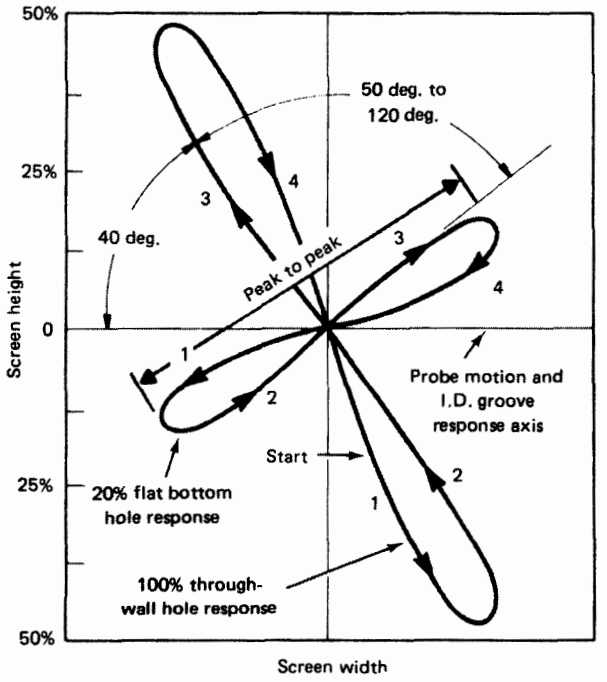


FIG. I-862-1 TYPICAL SIGNAL RESPONSE FROM A PROPERLY CALIBRATED DIFFERENTIAL BOBBIN COIL PROBE SYSTEM

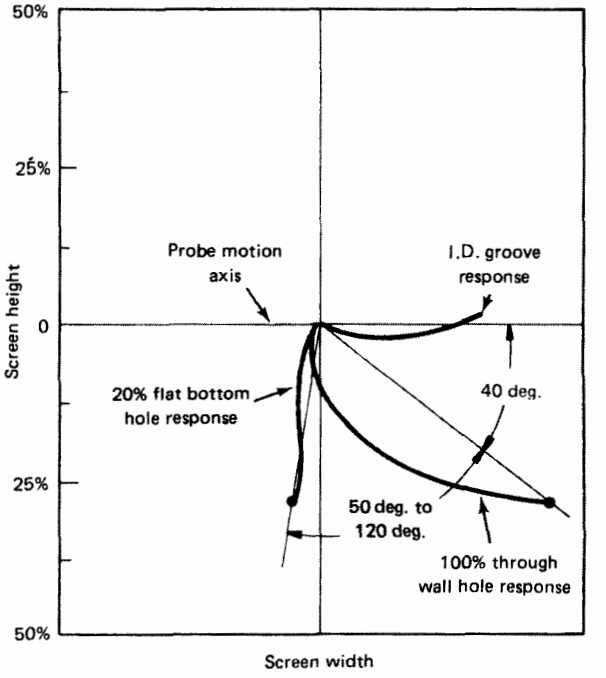


FIG. I-862-2 TYPICAL SIGNAL RESPONSE FROM A PROPERLY CALIBRATED ABSOLUTE BOBBIN COIL PROBE SYSTEM

(g) The dimensions of the calibration discontinuities and the applicable ET system response shall become part of the permanent record of the standard.

I-862 Basis Frequency[1] Calibration Procedure

The examination system shall be calibrated utilizing the standard described in I-861.

(a) Basis Frequency Calibration Using Differential Bobbin Coil Technique

(1) Adjust the ET instrument for a basis frequency chosen so that the phase angle of a signal from the four 20% flat bottom holes is between 50 deg. and 120 deg. rotated clockwise from the signal of the through-the-wall hole (Fig. I-862-1).

(2) The trace display for the four 20% flat bottom holes shall be generated, when pulling the probe, in the directions illustrated in Fig. I-862-1: down and to the left first, followed by an upward motion to the right, followed by a downward motion returning to the point of origin.

(3) The sensitivity shall be adjusted to produce a minimum peak-to-peak signal from the four 20% flat bottom holes of 30% of the full scale horizontal presentation with the oscilloscope sensitivity set at 1 V per division.

(4) Adjust the phase or rotation control so that the signal response due to probe motion, or the 10% deep circumferential inside diameter groove, or both, is positioned along the horizontal axis of the display ±5 deg. The responses from the calibration holes shall be maintained as described in (a)(1), (2), and (3) above.

(b) Basis Frequency Calibration Using Absolute Bobbin Coil Technique

(1) Adjust the ET instrument for a basis frequency so that the phase angle between a line drawn from the origin to the tip of the response from the through-the-wall hole and the horizontal axis is approximately 40 deg. The phase angle formed by a line drawn from the origin to the tip of the response of the four 20% flat bottom holes and the through-the-wall response line is between 50 deg. and 120 deg. (see Fig. I-862-2).

(2) The sensitivity shall be adjusted to produce a minimum origin-to-peak signal from the four 20% flat bottom holes of 30% of the full scale horizontal presentation with the oscilloscope sensitivity set at 1 V per division.

[1] The basis frequency is that test frequency selected for the examination which provides responses from the 20% flat bottom holes and the 100% through-the-wall hole references in the calibration tube standard that have a phase angle difference between 50 deg and 120 deg.

(3) Adjust the phase or rotation control so that the signal response due to probe rotation, or the 10% deep circumferential inside diameter groove, or both, is positioned along the horizontal axis of the display ±5 deg. The response of the calibration reference shall be maintained as described in (b)(1) and (2) above.

(4) The response may be rotated to the upper quadrants of the display at the option and convenience of the operator.

(5) Repeat withdrawing the probe through the calibration tube standard at the probe speed selected for the examination. Record the responses of the applicable calibration discontinuities. Ascertain that they are clearly indicated by the instrument and are distinguishable from each other as well as from probe motion signals.

I-863 Auxiliary Frequency(s) Calibration Procedure

(a) Auxiliary frequency(s) may be used to examine the tube wall. Reference standards other than that specified in I-861 may be used to establish examination specific sensitivity settings and an impedance plane phase reference.

(b) Auxiliary frequency(s) may be combined (mixed) with the basis frequency or with each other for extraneous variable suppression. When auxiliary frequency(s) are combined with the basis frequency for extraneous variable suppression, the basis frequency shall meet the requirements of I-862.

(c) Reference standards simulating the extraneous variables shall be used to establish mixing parameters. Auxiliary frequency response to the extraneous variable reference standard, or basis frequency response to the extraneous variable reference standard, or both, shall be a part of the calibration record.

(d) Repeat withdrawing the probe through the calibration standard at the probe speed selected for examination. Record the auxiliary frequency response of the applicable reference discontinuities.

(e) The basis frequency and auxiliary frequencies shall be recorded.

I-864 Calibration Confirmation

(a) Calibration shall include the complete ET examination system. Any change of probe, extension cables, ET instrument, recording instruments, or any other parts of the ET examination system hardware shall require recalibration.

(b) The system calibration hardware shall be confirmed as required by the referencing Code Section.

(c) Should the system be found to be out of calibration (as defined in I-862) the equipment shall be recalibrated. The recalibration shall be noted on the recording. The data analyst shall determine which tubes, if any, shall be re-examined.

I-865 Correlation of Signals to Estimate Depth of Discontinuities

The depth of discontinuities is primarily shown by the phase angle of the ET signal they produce. A relationship of reference comparator depths versus signal phase angle shall be developed for the examination being performed (see Fig. I-865-1). The following reference comparators may be used.

(a) The reference comparators shall be manufactured from a length of tubing of the same nominal size (diameter and wall thickness) and material (chemical composition and product form) as the tubes being examined.

(b) The reference comparators may be flat bottom holes drilled to varying depths.

(c) The drilled holes in the calibration standard (see I-861) may be used to establish this relationship where additional depths are required.

(d) The tolerance for the dimensions of the flat bottom holes shall be the same as those specified for the calibration tube standards [see I-861(g)].

(e) Except for the holes specified in (f)(1) below, all references shall be far enough apart to avoid interference between signals.

(f) When drilled holes are used, the dimensions shall be as follows:

(1) four flat bottom drill holes, $^{3}/_{16}$ in. (5 mm) diameter, 20% through the wall [same as the calibration tube standard (b) in I-861(b)];

(2) one flat bottom drill hole, $^{3}/_{16}$ in. (5 mm) in diameter × 40% through the wall from the outside surface;

(3) one flat bottom drill hole, $^{7}/_{64}$ in. (2.8 mm) in diameter × 60% through the wall from the outside surface;

(4) one flat bottom drill hole, $^{5}/_{64}$ in. (2.0 mm) in diameter × 80% through the wall from the outside surface;

(5) one through-the-wall drill hole [same as the calibration tube standard in I-861(a)].

(g) Other reference comparators may be used, provided that they can be demonstrated to be comparable to the intended discontinuity to be evaluated.

(h) Signal amplitude may be used to estimate depth for defects, which exhibit a known regularity in their growth history. Standards representative of the defect

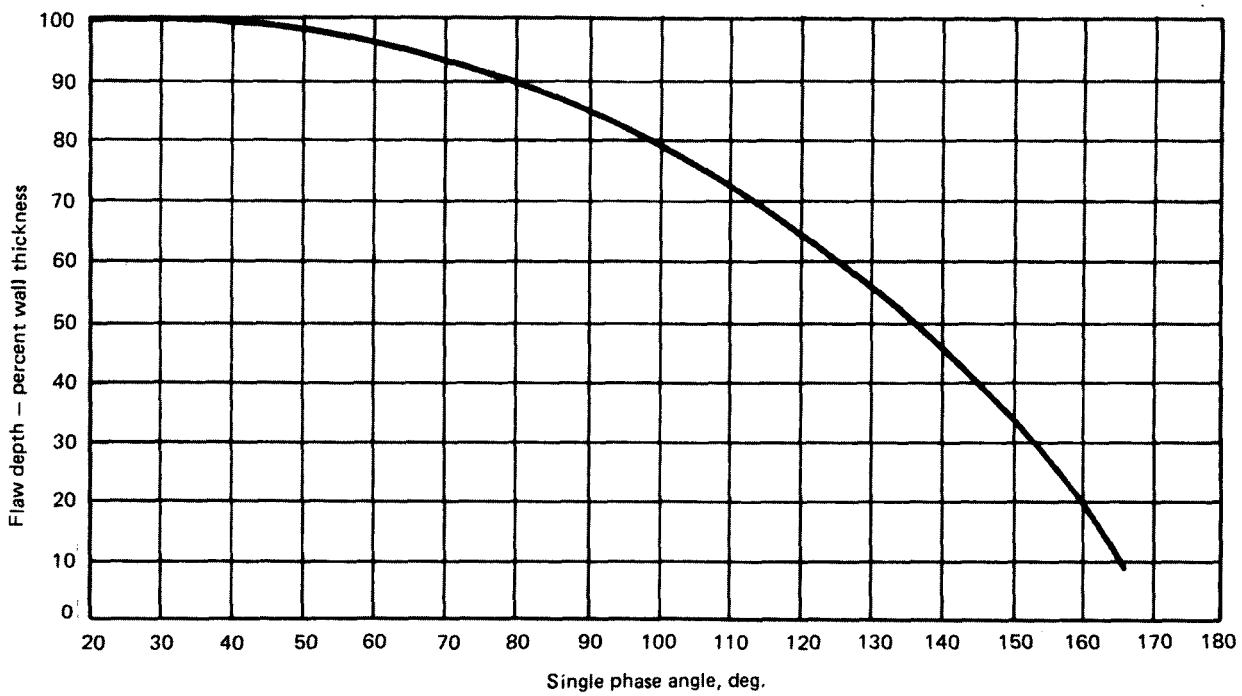


FIG. I-865-1 PHASE ANGLE vs FLAW DEPTH INCONEL TUBE, 400 kHz (TYPICAL 0.050 in. WALL TUBE)

shall be used to generate an amplitude versus depth calibration curve.

I-870 EXAMINATION

I-871 General

Data shall be recorded as the probe traverses the tube.

I-872 Probe Speed

The nominal probe speed during examination shall not exceed 14 in./s (350 mm/s). Higher probe speeds may be used if system frequency response and sensitivity to the applicable calibration standards described in I-861 can be demonstrated.

I-880 EVALUATION

I-881 General

The evaluation of examination data shall be made in accordance with the referencing Code Section.

I-890 DOCUMENTATION

I-891 Procedure Requirements

When required by the referencing Code Section, Eddy Current (ET) examinations shall be performed in accordance with a written procedure. Each procedure shall include at least the following information:

(a) tube material, diameter, and wall thickness;

(b) size and type of probes;

(c) mode of operation (differential or absolute or both);

(d) examination frequency or frequencies;

(e) manufacturer and model of ET equipment;

(f) scanning speed during examination;

(g) examination technique, i.e., hand probe, mechanized probe drive, remote control fixture, etc.;

(h) calibration procedure and calibration tube standards;

(i) data recording equipment and procedures;

(j) procedure for interpretation of results;

(k) additional information as necessary to describe the examination.

ARTICLE 8
MANDATORY APPENDICES

APPENDIX II — EDDY CURRENT EXAMINATION OF NONFERROMAGNETIC HEAT EXCHANGER TUBING

II-810 SCOPE

This Appendix provides the requirements for bobbin coil, multifrequency, multiparameter, Eddy Current examination for nonferromagnetic heat exchanger tubing.

II-820 GENERAL

This Appendix also provides the methodology for examining nonferromagnetic, heat exchanger tubing using the eddy current method and bobbin coil technique. By scanning the tubing from the boreside, information will be obtained from which the condition of the tubing will be determined. Scanning is generally performed with a bobbin coil attached to a flexible shaft driven by a motorized device. Results are obtained by evaluating data recorded during scanning.

II-820.1 General Requirements

II-820.1.1 Procedure Requirements. Examinations shall be conducted in accordance with a written procedure. Each procedure shall include the following information:

(a) tube material, diameter and wall thickness;

(b) size and type of probes, including manufacturer's name, description or part number, and length of probe and probe extension cables;

(c) examination frequencies;

(d) manufacturer and model of eddy current equipment;

(e) scanning direction and speed during examination (insertion, retraction, or both — from inlet or outlet end);

(f) inspection technique, e.g., hand probe, mechanized probe driven, remote control fixture;

(g) description of calibration procedure and calibration standards;

(h) description of data recording equipment and procedures;

(i) procedure for analysis of examination results and applicable criteria for reportable indications;

(j) procedure for reporting examination results, e.g., 3 digit codes or reference points;

(k) personnel requirements;

(l) fixture location verification.

II-820.1.2 Personnel Requirements. Nondestructive examination personnel shall be qualified in accordance with the requirements of the referencing Code Section.

II-830 EQUIPMENT

II-830.1 Data Acquisition System

II-830.1.1 General System Requirements

(a) The eddy current instrument shall have the capability of generating multiple frequencies simultaneously or multiplexed and be capable of multiparameter signal combination. In the selection of frequencies, consideration shall be given to optimizing flaw detection and characterization.

(b) The outputs from the eddy current instrument shall provide phase and amplitude information.

(c) The eddy current equipment shall be capable of detecting and recording dimensional changes, metallurgical changes and foreign material deposits, and responses from flaws originating on either tube wall surface.

II-830.2 Analog Data Acquisition System

II-830.2.1 Eddy Current Instrument

(a) The frequency response of the outputs from the eddy current instrument shall be constant within ±2% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-in./s) [0.4 (Hz-mm/s)] times maximum probe travel speed (in./sec) (mm/s).

(b) Eddy current signals shall be displayed as two-dimensional patterns by use of an X-Y storage oscilloscope or equivalent.

(c) The frequency response of the instrument output shall be constant within ±2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-in./s) [0.4 (Hz-mm/s)] times maximum probe travel speed.

II-830.2.2 Magnetic Tape Recorder

(a) The magnetic tape recorder shall be capable of recording and playing back eddy current signal data from all test frequencies and shall have voice logging capability.

(b) The frequency response of the magnetic tape recorder outputs shall be constant within ±10% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-in./s) [0.4 (Hz-mm/s)] times maximum probe travel speed.

(c) Signal reproducibility from input to output shall be within ±5%.

II-830.2.3 Strip Chart Recorder

(a) Strip chart recorders used during the examination shall have at least 2 channels.

(b) The frequency response of the strip chart recorder shall be constant within ±20% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-s/in.) [0.4 (Hz-s/mm)] times maximum probe travel speed.

II-830.3 Digital Data Acquisition System

II-830.3.1 Eddy Current Instrument

(a) At the scanning speed to be used, the sampling rate of the instrument shall result in a minimum digitizing rate of 30 samples per in. (25 mm) of examined tubing, using dr = sr/ss, where dr is the digitizing rate in samples per in., sr is the sampling rate in samples per sec or Hz, and ss is the scanning speed in in. per sec.

(b) The digital eddy current instrument shall have a minimum resolution of 12 bits per data point.

(c) The frequency response of the outputs of analog portions of the eddy current instrument shall be constant within ±2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-in./s) [0.4 (Hz-mm/s)] times maximum probe travel speed.

(d) The display shall be selectable so that the examination frequency or mixed frequencies can be presented as a Lissajous pattern.

(e) The Lissajous display shall have a minimum resolution of 7 bits full scale.

(f) The strip chart display shall be capable of displaying at least 2 traces.

(g) The strip chart display shall be selectable so either the X or Y component can be displayed.

(h) The strip chart display shall have a minimum resolution of 6 bits full scale.

II-830.3.2 Recording System

(a) The recording system shall be capable of recording and playing back all acquired eddy current signal data from all test frequencies.

(b) The recording system shall be capable of recording and playing back text information.

(c) The recording system shall have a minimum resolution of 12 bits per data point.

II-830.4 Bobbin Coils

II-830.4.1 General Requirements

(a) Bobbin coils shall be able to detect calibration standard discontinuities.

(b) Bobbin coils shall have sufficient bandwidth for operating frequencies selected for flaw detection and sizing.

II-830.5 Data Analysis System

II-830.5.1 General System Requirements

(a) The data analysis system shall be capable of displaying eddy current signal data from all test frequencies.

(b) The system shall have multiparameter mixing capability.

(c) The system shall be capable of maintaining the identification of each tube recorded.

(d) The system shall be capable of measuring phase angles in increments of one degree or less.

(e) The system shall be capable of measuring amplitudes to the nearest 0.1 volt.

II-830.6 Analog Data Analysis System

II-830.6.1 Display. Eddy current signals shall be displayed as Lissajous patterns by use of an X-Y storage display oscilloscope or equivalent. The frequency response of the display device shall be constant within ±2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-in./s) [0.4 (Hz-mm/s)] times maximum probe travel speed.

II-830.6.2 Recording System

(a) The magnetic tape recorder shall be capable of playing back the recorded data.

(b) The frequency response of the magnetic tape recorder outputs shall be constant within ±10% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-in./s) [0.4 (Hz-mm/s)] times maximum probe travel speed (in./s) (mm/s).

(c) Signal reproducibility input to output shall be within ±5%.

II-830.7 Digital Data Analysis System

II-830.7.1 Display

(a) The analysis display shall be capable of presenting recorded eddy current signal data and text information.

(b) The analysis system shall have a minimum resolution of 12 bits per data point.

(c) The Lissajous pattern display shall have a minimum resolution of 7 bits full scale.

(d) The strip chart display shall be selectable so either the X or Y component of any examination frequency or mixed frequencies can be displayed.

(e) The strip chart display shall have a minimum resolution of 6 bits full scale.

II-830.7.2 Recording System

(a) The recording system shall be capable of playing back all recorded eddy current signal data and text information.

(b) The recording system shall have a minimum resolution of 12 bits per data point.

II-830.8 Hybrid Data Analysis System

(a) For a hybrid system using both digital elements and some analog elements, individual elements shall meet II-830.1 and either II-830.2 or II-830.3, as applicable.

(b) If analog to digital or digital to analog converters are used, the frequency response of the analog element outputs shall be constant within ±5% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 (Hz-in./s) [0.4 (Hz-mm/s)] times maximum probe travel speed.

II-840 REQUIREMENTS

II-840.1 General Requirements

(a) The eddy current signal data from all test frequencies shall be recorded on the recording media as the probe traverses the tube.

(b) The sensitivity for the differential bobbin coil technique shall be sufficient to produce a response from the through-wall holes with a minimum vertical amplitude of 50% of the full Lissajous display height.

II-840.2 Probe Traverse Speed. The traverse speed shall not exceed that which provides adequate frequency response and sensitivity to the applicable calibration discontinuities.

II-840.3 Fixture Location Verification

(a) The ability of the fixture to locate specific tubes shall be verified visually and recorded upon installation of the fixture and before relocating or removing the fixture.

(b) When the performance of fixture location reveals that an error has occurred in the recording of probe verification location, the tubes examined since the previous location verification shall be re-examined.

II-840.4 Automated Data Screening System. When automated eddy current data screening systems are used, each system shall be qualified in accordance with a written procedure.

II-860 CALIBRATION

II-860.1 Equipment Calibration

II-860.1.1 Analog Equipment

The following shall be verified by annual calibration.

(a) The oscillator output frequency to the drive coil shall be within ±5% of its indicated frequency.

(b) The vertical and horizontal linearity of the cathode ray tube (CRT) display shall be within ±10% of the deflection of the input voltage.

(c) The CRT vertical and horizontal trace alignment shall be within ±2 deg. of parallel to the graticule lines.

(d) The ratio of the output voltage from the tape recorder shall be within ±5% of the input voltage for each channel of the tape recorder.

(e) The chart speed from the strip chart recorder shall be within ±5% of the indicated value.

(f) Amplification for all channels of the eddy current instrument shall be within 5% of the mean value, at all sensitivity settings, at any single frequency.

(g) The two output channels of the eddy current instrument shall be orthogonal within ±3 deg. at the examination frequency.

II-860.1.2 Digital Equipment. Analog elements of digital equipment shall be calibrated in accordance with II-860.1.1. Digital elements need not be calibrated.

II-860.2 Calibration Standards

II-860.2.1 General Requirements. Calibration standards shall conform to the following:

(a) Calibration standards shall be manufactured from a tubing of the same material specification, same heat treatment, and same nominal size as that to be examined in the vessel.

(b) Tubing calibration standard materials heat treated differently from the tubing to be examined may be used when signal responses from the discontinuities described in II-860.2.2 are demonstrated to the Inspector to be equivalent in both the calibration standard and tubing of the same heat treatment as the tubing to be examined.

(c) As an alternative to (a) and (b), calibration standards fabricated from UNS Alloy N06600 shall be manufactured from a length of tubing of the same material specification and same nominal size as that to be examined in the vessel.

(d) Discontinuities in calibration standards shall be spaced axially so they can be differentiated from each other and from the end of the tube. The as-built dimensions of the discontinuities and the applicable Eddy Current equipment response shall become part of the permanent record of the standard.

II-860.2.2 Calibration Standards for Differential and Absolute Bobbin Coil

(a) Calibration standards shall contain:

(1) One or both through-wall holes as follows:

(a) A 0.052 in. (1.3 mm) diameter hole for tubing with diameters of 0.750 in. (19 mm) and less, or a 0.067 in. (1.70 mm) hole for tubing with diameters greater than 0.750 in. (19 mm).

(b) Four holes spaced 90 deg. apart in a single plane around the tube circumference, 0.026 in. (0.65 mm) diameter for tubing with diameters of 0.750 in. (19 mm) and less and 0.033 in. (0.83 mm) diameter for tubing with diameters greater than 0.750 in. (19 mm).

(2) A flat-bottom hole 0.109 in. (2.7 mm) diameter, 60% through the tube wall from the outer surface.

(3) A flat-bottom hole $^{3}/_{16}$ in. (5 mm) diameter, 40% through the tube wall from the outer surface.

(4) Four flat-bottom holes $^{3}/_{16}$ in. (5 mm) diameter, spaced 90 deg. apart in a single plane around the tube circumference, 20% through the tube wall from the outer surface.

(b) The depth of the artificial discontinuities, at their center, shall be within ±20% of the specified depth or ±0.003 in. (±0.08 mm), whichever is less. All other dimensions shall be within ±0.03 in. (±0.8 mm).

(c) All artificial discontinuities shall be sufficiently separated to avoid interference between signals, except for the holes specified in (a)(1)(b) and (a)(4).

II-860.3 Analog System Calibration

II-860.3.1 Differential Bobbin Coil Technique

(a) The sensitivity shall be adjusted to produce a minimum peak-to-peak signal of 4 volts from the four 20% flat-bottom holes or 6 volts from the four through-wall drilled holes.

(b) The phase or rotation control shall be adjusted so the signal response due to the through-wall hole forms down and to the right first as the probe is withdrawn from the standard holding the signal response from the probe motion horizontal.

(c) Withdraw the probe through the calibration standard at the nominal examination speed. Record the responses of the applicable calibration discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

II-860.3.2 Absolute Bobbin Coil Technique

(a) The sensitivity shall be adjusted to produce a minimum origin-to-peak signal of 2 volts from the four 20% flat-bottom holes or 3 volts from the four through-wall drilled holes.

(b) Adjust the phase or rotation control so that the signal response due to the through-wall hole forms up and to the left as the probe is withdrawn from the standard holding the signal response from the probe motion horizontal.

(c) Withdraw the probe through the calibration standard at the nominal examination speed. Record the responses of the applicable calibration discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

II-860.4 Digital System Calibration. When the eddy current examination information is digitized and recorded for off-line analysis and interpretation, the system calibration phase and amplitude settings shall be performed off-line by the data analyst. Phase and amplitude settings shall be such that the personnel acquiring the data can clearly discern that the eddy current instrument is working properly.

II-860.4.1 System Calibration Verification

(a) Calibration shall include the complete eddy current examination system. Any change of probe, extension cables, eddy current instrument, recording instruments, or any other parts of the eddy current examination system hardware shall require recalibration.

(b) System calibration verification shall be performed and recorded at the beginning and end of each unit of data storage of the recording media.

(c) Should the system be found to be out of calibration (as defined in II-860.3), the equipment shall be recalibrated. The recalibration shall be noted on the recording and the data analyst shall determine which tubes, if any, shall be reexamined.

II-880 EVALUATION

II-880.1 Data Evaluation. Data shall be evaluated in accordance with the requirements of this Article.

II-880.2 Means of Determining Indication Depth. For indication types that must be reported in terms of depth, a means of correlating the indication depth with the signal amplitude or phase shall be established. The means of correlating the signal amplitude or phase with the indication depth shall be based on the basic calibration standard or other representative standards that have been qualified. This shall be accomplished by using curves, tables, or software.

II-880.3 Frequencies Used for Data Evaluation. All indications shall be evaluated. Indication types, which must be reported, shall be characterized using the frequencies or frequency mixes that were qualified.

II-890 DOCUMENTATION

II-890.1 Reporting

II-890.1.1 Criteria. Indications reported in accordance with the requirements of this Article shall be described in terms of the following information, as a minimum:

(a) location along the length of the tube and with respect to the support members

(b) depth of the indication through the tube wall, when required by this Article

(c) signal amplitude

(d) frequency or frequency mix from which the indication was evaluated

II-890.1.2 Depth. The maximum evaluated depth of flaws shall be reported in terms of percentage of loss of tube wall. When the loss of tube wall is determined by the analyst to be less than 20%, the exact percentage of tube wall loss need not be recorded, i.e., the indication may be reported as being less than 20%.

II-890.1.3 Non-Quantifiable Indications. A non-quantifiable indication is a reportable indication that cannot be characterized. The indication shall be considered a flaw until otherwise resolved.

II-890.1.4 Support Members

II-890.1.4.1 Location of Support Members. The location of support members used as reference points for the eddy current examination shall be verified by fabrication drawings or the use of a measurement technique.

II-890.2 Records

II-890.2.1 Record Identification. The recording media shall contain the following information within each unit of data storage:

(a) owner

(b) plant site

(c) heat exchanger identification

(d) data storage unit number

(e) date of examination

(f) serial number of the calibration standard

(g) operator's identification and certification level

(h) examination frequencies

(i) lengths of probe and probe extension cables

(j) size and type of probes

(k) probe manufacturer's name and manufacturer's part number or probe description

II-890.2.2 Tube Identification

(a) Each tube examined shall be identified on the applicable unit of data storage

(b) The method of recording the tube identification shall correlate tube identification with corresponding recorded tube data.

II-890.2.3 Reporting

(a) The Owner or his agent shall prepare a report of the examinations performed. The report shall be prepared, filed, and maintained in accordance with the referencing Code Section. Procedures and equipment used shall be identified sufficiently to permit comparison of the examination results with new examination results run at a later date. This shall include initial calibration data for each eddy current examination system and subsequent rechecks.

(b) The report shall include a record indicating the tubes examined (this may be marked on a tubesheet sketch or drawing), any scanning limitations, the location and depth of each reported flaw, and the identification and certification level of the operators and data evaluators that conducted each examination or part thereof.

(c) Tubes that are to be repaired or removed from service, based on eddy current examination data, shall be identified.

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MANDATORY APPENDICES

APPENDIX III — EDDY CURRENT (ET) EXAMINATION ON COATED FERRITIC MATERIALS

III-810 SCOPE

(a) This Appendix provides the Eddy Current examination methodology and equipment requirements applicable for performing Eddy Current examination on coated ferritic materials.

(b) Article 1, General Requirements, also applies when Eddy Current examination of coated ferritic materials is required. Requirements for written procedures, as specified in Article 8, shall apply, as indicated.

(c) SD-1186, Standard Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base, may be used to develop a procedure for measuring the thickness of nonmagnetic and conductive coatings.

III-820 GENERAL

III-821 Personnel Qualification

NDE personnel shall be qualified in accordance with the requirements of the referencing Code Section.

III-822 Procedure

The requirements of T-823 shall apply. The type of coating and maximum coating thickness shall be essential variables.

III-823 Procedure Demonstration

The procedure shall be demonstrated to the satisfaction of the Inspector in accordance with requirements of the referencing Code Section.

III-830 EQUIPMENT

The ET system shall include phase and amplitude display.

III-850 TECHNIQUE

III-851 Coating Thickness Measurement

The performance of examinations shall be preceded by measurement of the coating thickness in the areas to be examined. If the coating is nondconductive, an Eddy Current technique may be used to measure the coating thickness. If the coating is conductive, a magnetic coating thickness technique may be used in accordance with SD-1186. Coating thickness measurement shall be used in accordance with the equipment manufacturer's instructions. Coating thickness measurements shall be taken at the intersections of a 2 in. (50 mm) maximum grid pattern over the area to be examined. The thickness shall be the mean of three separate readings within $\frac{1}{4}$ in. (6 mm) of each intersection.

III-852 Procedure Verification

(a) A qualification specimen is required. The material used for the specimen shall be the same specification and heat treatment as the coated ferromagnetic material to be examined. If a conductive primer was used on the material to be examined, the primer thickness on the procedure qualification specimen shall be the maximum allowed on the examination surfaces by the coating specification. Plastic shim stock may be used to simulate nonconductive coatings for procedure qualification. The thickness of the coating or of the alternative plastic shim stock on the procedure qualification specimen shall be equal to or greater than the maximum coating thickness measured on the examination surface.

(b) The qualification specimen shall include at least one crack. The length of the crack open to the surface shall not exceed the allowable length for surface flaws. The maximum crack depth in the base metal shall be between 0.020 and 0.040 in. (0.5 mm and 1.0 mm). In addition, if the area of interest includes weld metal, a 0.020 in. (0.5 mm) maximum depth crack is required in an as-welded and coated surface typical of the welds to be examined. In lieu of a crack, a machined notch of 0.010 in. (0.25 mm) maximum width and 0.020 in. (0.5 mm) maximum depth may be used in the as-welded surface.

(c) Examine the qualification specimen first uncoated and then after coating to the maximum thickness to be qualified. Record the signal amplitudes from the qualification flaws.

(d) Using the maximum scanning speed, the maximum scan index, and the scan pattern specified by the procedure, the procedure shall be demonstrated to consistently detect the qualification flaws through the maximum coating thickness regardless of flaw orientation (e.g., perpendicular, parallel, or skewed to the scan direction). The signal amplitude from each qualification flaw in the coated qualification specimen shall be at least 50% of the signal amplitude measured on the corresponding qualification flaw prior to coating.

III-870 EXAMINATION

(a) Prior to the examination, all loose, blistered, flaking, or peeling coating shall be removed from the examination area.

(b) When conducting examinations, areas of suspected flaw indications shall be confirmed by application of another surface or volumetric examination method. It may be necessary to remove the surface coating prior to performing the other examination.

III-890 DOCUMENTATION

III-891 Examination Report

The report of examination shall contain the following information:

(a) a procedure identification and revision

(b) examination personnel identity, and, when required by the referencing Code Section, qualification level

(c) date of examination

(d) results of examination and related sketches or maps of rejectable indications

(e) identification of part or component examined

III-892 Performance Demonstration Report

Performance demonstrations shall be documented and contain the following information:

(a) identification of the procedure

(b) identification of personnel performing and witnessing the qualification

(c) descriptions and drawings or sketches of the qualification specimen and calibration reference standards, including coating thickness measurement and flaw dimensions

(d) calibration sensitivity details

(e) qualification results, including maximum coating thickness and flaws detected

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APPENDIX IV — GLOSSARY OF TERMS FOR EDDY CURRENT EXAMINATION

IV-810 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms related to Eddy Current examination, which appears in Article 8.

IV-820 GENERAL REQUIREMENTS

(a) This standard terminology for nondestructive examination ASTM E 1316 has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 6, Electromagnetic Testing, provides the definitions of terms listed in IV-830(a).

(c) For general terms, such as *Interpretation, Flaw, Discontinuity, Evaluation,* etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph IV-830(b) provides a list of terms and definitions, which are in addition to SE-1316 and are Code specific.

IV-830 REQUIREMENTS

(a) The following SE-1316 terms are used in conjunction with this Article: *absolute coil, differential coils, eddy current, eddy current testing, frequency, phase angle, probe coil, reference standard, standard.*

(b) The following Code terms are used in conjunction with this Article.

bobbin coil — for inspection of tubing, a bobbin coil is defined as a circular inside diameter coil wound such that the coil is concentric with a tube during examination

text information — information stored on the recording media to support recorded eddy current data. Examples include tube and steam generator identification, operator's name, date of examination, and results.

unit of data storage — each discrete physical recording medium on which eddy current data and text information are stored. Examples include tape cartridge, floppy disk, etc.

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MANDATORY APPENDICES

04

APPENDIX V — EDDY CURRENT MEASUREMENT OF NONCONDUCTIVE-NONMAGNETIC COATING THICKNESS ON A NONMAGNETIC METALLIC MATERIAL

V-810 SCOPE

This Appendix provides requirements for absolute surface probe measurement of nonconductive-nonmagnetic coating thickness on a nonmagnetic metallatic material.

V-820 GENERAL

This Appendix provides a technique for measuring nonconductive-nonmagnetic coating thicknesses on a nonmagnetic metallic substrate. The measurements are made with a surface probe with the lift-off calibrated for thickness from the surface of the test material. Various numbers of thickness measurements can be taken as the probe's spacing from the surface is measured. Measurements can be made with various types of measurements.

V-821 Written Procedure Requirements

V-821.1 Requirements. Eddy current examination shall be performed in accordance with a written procedure, which shall, as a minimum, contain requirements listed in Table V-821. The written procedure shall establish a single value, or range of values, for each requirement.

V-821.2 Procedure Qualification/Technique Validation. When procedure qualification is specified, a change of requirement in Table V-821 identified as an essential variable shall require requalification of written procedure by demonstration. A change of a requirement identified as a nonessential variable, does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

TABLE V-821
REQUIREMENTS OF AN EDDY CURRENT EXAMINATION PROCEDURE FOR THE MEASUREMENT OF NONCONDUCTIVE-NONMAGNETIC COATING THICKNESS ON A METALLIC MATERIAL

Requirement	Essential Variable	Non-Essential Variable
Examination Frequency	X	
Absolute Mode	X	
Size and Probe Type(s), Manufacturer's Name and Description	X	
Substrate Material	X	
Equipment Manufacturer/Model	X	
Cabling (Type and Length)	X	
Nonconductive Calibration Material (Nonconductive Shims)		X
Personnel Qualification Requirements Unique to this Technique		X
Reference to the Procedure Qualification Records		X

V-822 Personnel Qualification

Personnel qualification requirements shall be in accordance with the referencing Code Section.

V-823 Procedure/Technique Demonstration

The procedure/technique shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

V-830 EQUIPMENT

The eddy current instrument may have a storage type display for phase and amplitude or it may contain an analog or digital meter. The frequency range of the instrument shall be adequate for the material and the coating thickness range.

V-831 Probes

The eddy current absolute probe shall be capable of inducing alternating currents into the material and sensing changes in the separation (lift-off) between the contact surface of the probe and the substrate material.

V-850 TECHNIQUE

A single frequency technique shall be used with a suitable calibration material such as nonconductive shim(s), paper or other nonconductive nonmagnetic material. The shims or other material thicknesses shall be used to correlate a position on the impedance plane or meter reading with the nonconductive material thicknesses and the no thickness position or reading when the probe is against the bare metal. If the thickness measurement is used only to assure a minimum coating thickness, then only a specimen representing the minimum thickness need be used.

V-860 CALIBRATION

The probe frequency and gain settings shall be selected to provide a suitable and repeatable signal. The probe shall be nulled on the bare metal.

(a) Impedance Plane Displays. For instruments with impedance plane displays, gains on the vertical and horizontal axes shall be the same value. The phase or rotation control and the gain settings shall be adjusted so that the bare metal point (null) and the air pont are located at diagonally opposite corners of the display. A typical coating thickness calibration curve is illustrated in Fig. V-860.

(b) Meter Displays. For instruments with analog meter displays, the phase and gain controls shall be used to provide near full scale deflection between the bare metal and maximum coating thickness.

(c) All Instruments. For all instruments, the difference in meter readings or thickness positions on the screen shall be adequate to resolve a 10% change in the maximum thickness.

(d) Calibration Data. The screen positions or meter readings and the shim thicknesses shall be recorded along with the bare metal position or meter reading.

(e) Verification of Calibration. Calibration readings shall be verified every two hours. If during recalibration, a reading representing a coating thickness change greater than ±10% from the prior calibration is observed, examinations made after the prior calibration shall be repeated.

V-870 EXAMINATION

Coating thickness measurements shall be taken at individual points as indicated in the referencing Code Section. If it is desired to measure the minimum coating thickness or maximum coating thickness on a surface, a suitable grid pattern shall be established and measurements shall be taken at the intersections of the grid pattern. Measurements shall be recorded.

V-880 EVALUATION

Coating thicknesses shall be compared with the acceptance standards of the referencing Code Section.

V-890 DOCUMENTATION

V-891 Examination Report

The report of the examination shall contain the following information:

(a) a procedure identification and revision,

(b) examination personnel identity, and, when required by the referencing Code Section, qualification level,

(c) date of examination,

(d) results of examination and related sketches or maps of thickness measurements,

(e) identification of part or component examined.

V-892 Performance Demonstration Report

When performance demonstration is required, it shall be documented and contain the following information:

(a) identification of the procedure,

(b) identification of the personnel performing and witnessing the qualification,

(c) coating thickness materials and base material,

(d) frequency, gain and rotation settings as applicable,

(e) qualification results, maximum coating thickness measured.

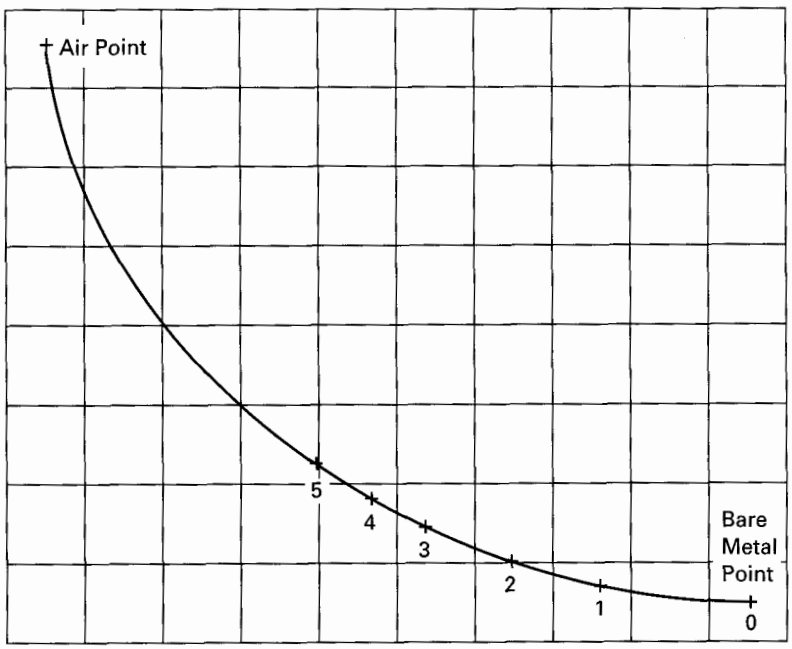

FIG. V-860 TYPICAL LIFT-OFF CALIBRATION CURVE FOR COATING THICKNESS SHOWING THICKNESS CALIBRATION POINTS ALONG THE CURVE

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MANDATORY APPENDICES

A05

APPENDIX VI — EDDY CURRENT DETECTION AND MEASUREMENT OF DEPTH OF SURFACE DISCONTINUITIES IN NONMAGNETIC METALS WITH SURFACE PROBES

VI-810 SCOPE

This Appendix provides the requirements for the detection and measurement of depth for surface discontinuities in nonmagnetic metallic materials using an absolute surface probe eddy current technique.

VI-820 GENERAL

This Appendix provides a technique for the detection and depth measurement of cracks and other surface discontinuities in nonmagnetic metal components. An absolute surface probe containing a single excitation coil is scanned over the surface of the examination object. When a surface discontinuity is encountered by the magnetic field of the probe, eddy currents generated in the material change their flow and provide a different magnetic field in opposition to the probe's magnetic field. Changes in the eddy current's magnetic field and the probe's magnetic field are sensed by the instrument and are presented on the instrument's impedance plane display. These instruments generally have capability for retaining the signal on the instrument's display where any discontinuity signal can be measured and compared to the calibration data.

VI-821 Written Procedure Requirements

VI-821.1 Requirements. Eddy current examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table VI-821. The written procedure shall establish a single value, or range of values, for each requirement.

A06 **VI-821.2 Procedure Qualification.** When procedure qualification is specified, a change of a requirement in Table VI-821 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

A06 TABLE VI-821
REQUIREMENTS OF AN EDDY CURRENT EXAMINATION PROCEDURE FOR THE DETECTION AND MEASUREMENT OF DEPTH FOR SURFACE DISCONTINUITIES IN NONMAGNETIC METALLIC MATERIALS

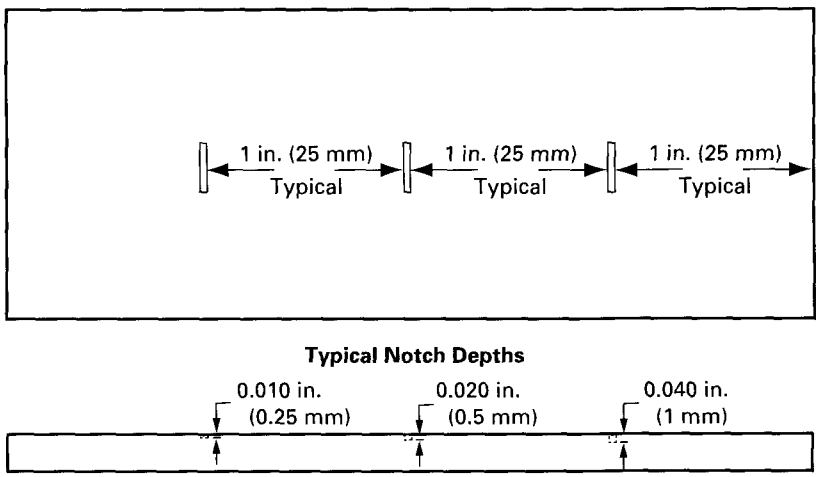
Requirement	Essential Variable	Non-Essential Variable
Examination frequency	X	...
Size and probe type(s), manufacturer's name and description	X	...
Material	X	...
Equipment manufacturer/model	X	...
Cabling (type and length)	X	...
Reference specimen and notch depths	X	...
Personnel qualification, when required by the referencing Code Section	X	...
Personnel qualification requirements unique to this technique	...	X
Reference to the procedure qualification records	...	X

VI-822 Personnel Qualification

Personnel qualification requirements shall be in accordance with the referencing Code Section.

VI-823 Procedure/Technique Demonstration

The procedure/technique shall be demonstrated to the satisfaction of the Inspector, in accordance with the requirements of the referencing Code Section.



GENERAL NOTES:
(a) Typical notch dimensions are 0.25 in. (6 mm) length x 0.010 in. (0.25 mm) width.
(b) Tolerances on notch dimensions are ±10% for length and width, and +10% and −20% for depth.

FIG. VI-832 REFERENCE SPECIMEN

VI-830 EQUIPMENT

The eddy current instrument shall have a storage-type display for phase and amplitude on an impedance plane. The frequency range of the instrument shall be adequate to provide for a suitable depth of penetration for the material under examination.

A06 VI-831 Probes

The eddy current absolute probe shall be capable of inducing alternating currents into the material and sensing changes in the depth of the notches in the reference specimen. The probe and instrument at the frequency to be used in the examination shall provide a signal amplitude for the smallest reference notch of a minimum of 10% full screen height (FSH). With the same gain setting for the smallest notch, the signal amplitude on the largest notch shall be a minimum of 50% FSH. If the amplitudes of the signals cannot be established as stated, other probe impedances or geometries (windings, diameters, etc.) shall be used.

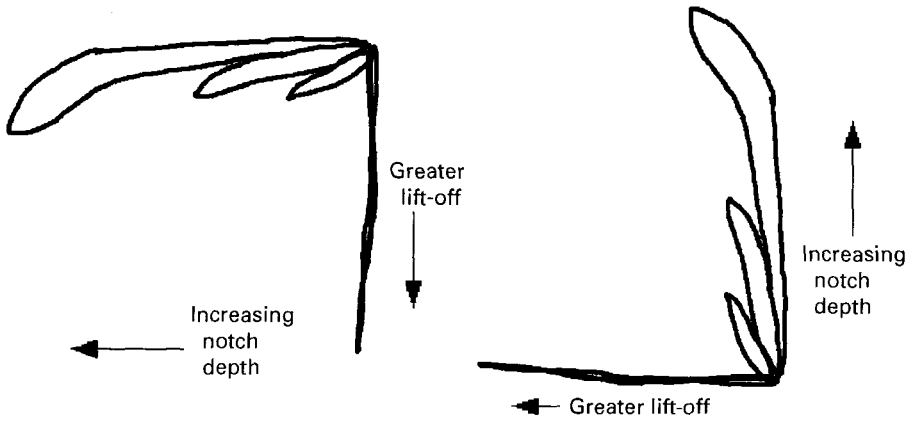
VI-832 Reference Specimen

A reference specimen shall be constructed of the same alloy as the material under examination. Minimum dimensions of the reference specimen shall be 2 in. (50 mm) by 4 in. (100 mm) and shall contain a minimum of two notches. Notch length shall be a minimum of 0.25 in. (6 mm) and notch depth shall be the minimum to be measured and the maximum depth allowed. If smaller length notches are required to be detected by the referencing Code Section, the reference specimen shall contain a smaller length notch meeting the referencing Code's requirements. The depth shall have a tolerance of +10% and −20% of the required dimensions. A typical reference specimen for measuring flaw depths in the range of 0.01 in. (0.25 mm) through 0.04 in. (1 mm) is shown in Fig. VI-832.

When curvature of the examination object in the area of interest is not flat and affects the lift-off signal, a reference specimen representing that particular geometry with the applicable notches shall be used.

VI-850 TECHNIQUE A06

A single-frequency technique shall be used. The frequency shall be selected to result in an impedance plane presentation that will result in a 90 deg phase shift between the lift-off signal and the flaw signals. The resulting signals will be displayed using an impedance plane presentation, with one axis representing the lift-off signal and the other axis representing the reference notch and flaw signal responses. The gain control on each axis displaying the flaw signals shall be adjusted to present amplitude for the flaw signal from the deepest notch to be at least 50% of the vertical or horizontal display it is presented on. Typical responses of the calibrated instrument are shown in Fig. VI-850. Note that the display may be rotated to show these indications in accordance with the procedure. Typically, the gain setting on the axis displaying the discontinuity signal will be higher than on



A06 FIG. VI-850 IMPEDANCE PLANE REPRESENTATIONS OF INDICATIONS FROM FIG. VI-832

the axis displaying lift-off. Discontinuity indications will be mostly vertical or horizontal (at 90 deg to lift-off). Any surface discontinuities in the examination specimen would provide similar indications.

A06 VI-860 CALIBRATION

The probe frequency and gain settings shall be selected to provide a suitable depth of penetration within the material, so that the depth of the deepest notch is distinguishable from the next smaller notch. The gain settings on the vertical and horizontal axes shall be set so that there is a dB difference, with the discontinuity depth gain being higher. The probe shall be nulled on the bare metal away from the notches. The *X–Y* position of the null point shall be placed on one corner of the screen. The phase or rotation control shall be adjusted so that when the probe is lifted off the metal surface, the display point travels at 90 deg to the discontinuity depth. Increase the vertical or horizontal gain, as applicable, if the smallest indication or the largest indication from the notches do not make 10% or 50% FSH, respectively. Maximum response from the notches is achieved when the probe is scanned perpendicular to the notch and centered on the notch. Differences in the vertical and horizontal gains may have to be adjusted. The screen indication lengths from the baseline (lift-off line) for each of the notch depths shall be recorded.

A06 VI-870 EXAMINATION

The area of interest shall be scanned, with overlap on the next scan to include at least 10% of the probe diameter. If the direction of suspected discontinuities is known, the scan direction shall be perpendicular to the long axis of the discontinuities. The object shall be scanned in two directions, 90 deg to each other. During the examination, the maximum scanning speed and lift-off distance shall not be greater than those used for calibration.

VI-880 EVALUATION A06

The discontinuity shall be scanned perpendicular to its long axis, to determine its maximum depth location and value. The maximum depth of any discontinuity detected shall be compared with the appropriate response of the reference specimen as specified in the referencing Code Section.

VI-890 DOCUMENTATION A06

VI-891 Examination Report A06

The report of the examination shall contain the following information:

(a) procedure identification and revision

(b) examination personnel identity and, when required by the referencing Code Section, qualification level

(c) date of examination

(d) results of examination and related sketches or maps of indications exceeding acceptance standard

(e) identification of part or component examined

(f) identification of reference specimen

(g) calibration results, and minimum and maximum discontinuity depths measured

VI-892 Performance Demonstration Report A06

When performance demonstration is required, it shall be documented with the following information:

(a) procedure identification and revision

(b) identification of the personnel performing and witnessing the demonstration

(c) base material and thickness

(d) frequency, gain, and rotation settings, as applicable

(e) demonstration results, and minimum and maximum discontinuity depths measured

(f) identification of reference specimen

VI-893 Record Retention A06

Records shall be maintained in accordance with requirements of the referencing Code Section.

ARTICLE 9
VISUAL EXAMINATION

T-910 SCOPE

(a) This Article contains methods and requirements for visual examination applicable when specified by a referencing Code Section. Specific visual examination procedures required for every type of examination are not included in this Article, because there are many applications where visual examinations are required. Some examples of these applications include nondestructive examinations, leak testing, in-service examinations and fabrication procedures.

(b) The requirements of Article 1, General Requirements, apply when visual examination, in accordance with Article 9, is required by a referencing Code Section.

(c) Definitions of terms for visual examination appear in Article 1, Appendix I – Glossary of Terms in Nondestructive Examination, and Article 9, Appendix I.

T-920 GENERAL

T-921 Written Procedure Requirements

T-921.1 Requirements. Visual examinations shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-921. The written procedure shall establish a single value, or range of values, for each requirement.

04 **T-921.2 Procedure Qualification.** When procedure qualification is specified, a change of a requirement in Table T-921 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-921.3 Demonstration. The procedure shall contain or reference a report of what was used to demonstrate that the examination procedure was adequate. In general, a fine line $\frac{1}{32}$ in. (0.8 mm) or less in width, an artificial imperfection or a simulated condition, located on the surface or a similar surface to that to be examined, may be considered as a method for procedure demonstration. The condition or artificial imperfection should be in the least discernable location on the area surface to be examined to validate the procedure.

TABLE T-921 04
REQUIREMENTS OF A VISUAL EXAMINATION PROCEDURE

Requirement (As Applicable)	Essential Variable	Non-Essential Variable
Change in technique used		
Direct to or from translucent	X	...
Direct to remote	X	...
Remote visual aids	X	...
Personnel performance requirements, when required	X	...
Lighting intensity (decrease only)	X	...
Configurations to be examined and base material product forms (pipe, plate, forgings, etc.)	...	X
Lighting equipment	...	X
Methods or tools used for surface preparation	...	X
Equipment or devices used for a direct technique	...	X
Sequence of examination	...	X
Personnel qualifications	...	X

T-922 Personnel Requirements

The user of this Article shall be responsible for assigning qualified personnel to perform visual examinations to the requirements of this Article. At the option of the manufacturer, he may maintain one certification for each product, or several separate signed records based on the area or type of work, or both combined. Where impractical to use specialized visual examination personnel, knowledgeable and trained personnel, having limited qualifications, may be used to perform specific examinations, and to sign the report forms. Personnel performing examinations shall be qualified in accordance with requirements of the referencing Code Section.

T-923 Physical Requirements

Personnel shall have an annual vision test to assure natural or corrected near distance acuity such that they are capable of reading standard J-1 letters on standard Jaeger test type charts for near vision. Equivalent near vision tests are acceptable.

T-930 EQUIPMENT

Equipment used for visual examination techniques, for example, direct, remote, or translucent, shall have the capabilities as specified in the procedure. Capabilities include, but are not limited to viewing, magnifying, identifying, measuring, and/or recording observations in accordance with requirements of the referencing Code Section.

T-950 TECHNIQUE

T-951 Applications

Visual examination is generally used to determine such things as the surface condition of the part, alignment of mating surfaces, shape, or evidence of leaking. In addition, visual examination is used to determine a composite material's (translucent laminate) subsurface conditions.

T-952 Direct Visual Examination

Direct visual examination may usually be made when access is sufficient to place the eye within 24 in. (600 mm) of the surface to be examined and at an angle not less than 30 deg. to the surface to be examined. Mirrors may be used to improve the angle of vision, and aids such as a magnifying lens may be used to assist examinations. Illumination (natural or supplemental white light) for the specific part, component, vessel, or section thereof being examined is required. The minimum light intensity at the examination surface/site shall be 100 footcandles (1000 lux). The light source, technique used, and light level verification is required to be demonstrated one time, documented, and maintained on file.

T-953 Remote Visual Examination

In some cases, remote visual examination may have to be substituted for direct examination. Remote visual examination may use visual aids such as mirrors, telescopes, borescopes, fiber optics, cameras, or other suitable instruments. Such systems shall have a resolution capability at least equivalent to that obtainable by direct visual observation.

T-954 Translucent Visual Examination

Translucent visual examination is a supplement of direct visual examination. The method of translucent visual examination uses the aid of artificial lighting, which can be contained in an illuminator that produces directional lighting. The illuminator shall provide light of an intensity that will illuminate and diffuse the light evenly through the area or region under examination. The ambient lighting must be so arranged that there are no surface glares or reflections from the surface under examination and shall be less than the light applied through the area or region under examination. The artificial light source shall have sufficient intensity to permit "candling" any translucent laminate thickness variations.

T-980 EVALUATION

T-980.1 All examinations shall be evaluated in terms of the acceptance standards of the referencing Code Section.

T-980.2 An examination checklist shall be used to plan visual examination and to verify that the required visual observations were performed. This checklist establishes minimum examination requirements and does not indicate the maximum examination which the Manufacturer may perform in process.

T-990 DOCUMENTATION

T-991 Report of Examination

T-991.1 A written report of the examination shall contain the following information:

(a) the date of the examination;

(b) procedure identification and revision used;

(c) technique used;

(d) results of the examination;

(e) examination personnel identity, and, when required by the referencing Code Section, qualification level;

(f) identification of the part or component examined.

T-991.2 Even though dimensions, etc., were recorded in the process of visual examination to aid in the evaluation, there need not be documentation of each viewing or each dimensional check. Documentation shall include all observation and dimensional checks specified by the referencing Code Section.

T-992 Performance Documentation

Documentation of performance demonstration shall be completed when required by the referencing Code Section.

T-993 Record Maintenance

Records shall be maintained as required by the referencing Code Section.

ARTICLE 9
MANDATORY APPENDIX

APPENDIX I — GLOSSARY OF TERMS FOR VISUAL EXAMINATION

I-910 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms related to Visual Examination which appear in Article 9.

I-920 GENERAL

(a) Article 30, SE-1316, Section 9, provides the definition of *footcandle (fc)*.

(b) Definitions of terms for visual examination and other methods appear in Article 1, Mandatory Appendix I, Glossary of Terms for Nondestructive Examination.

(c) The following Code terms are used in conjunction with Article 9:

artificial flaw — an intentional imperfection placed on the surface of a material to depict a representative flaw condition

auxiliary lighting — an artificial light source used as a visual aid to improve viewing conditions and visual perception

candling — see *translucent visual examination*

direct visual examination — a visual examination technique performed by eye and without any visual aids (excluding light source, mirrors, and/or corrective lenses)

enhanced visual examination — a visual examination technique using visual aids to improve the viewing capability, e.g., magnifying aids, borescopes, video probes, fiber optics, etc.

lux (Lx) — a unit of illumination equal to the direct illumination on a surface that is everywhere one meter from a uniform point source of one candle intensity or equal to one lumen per square meter

remote visual examination — a visual examination technique used with visual aids for conditions where the area to be examined is inaccessible for direct visual examination

surface glare — reflections of artificial light that interfere with visual examination

translucent laminate — a series of glass reinforced layers, bonded together, and having capabilities of transmitting light

translucent visual examination — a technique using artificial lighting intensity to permit viewing of translucent laminate thickness variations (also called candling)

visual examination — a nondestructive examination method used to evaluate an item by observation, such as: the correct assembly, surface conditions, or cleanliness of materials, parts, and components used in the fabrication and construction of ASME Code vessels and hardware

ARTICLE 10
LEAK TESTING

T-1000 INTRODUCTION

T-1010 SCOPE

This Article describes methods and requirements for the performance of leak testing.

(a) When a leak testing method or technique of Article 10 is specified by a referencing Code Section, the leak test method or technique shall be used together with Article 1, General Requirements.

(b) Definition of terms used in this Article are in Mandatory Appendix VII of this Article.

(c) The test methods or techniques of these methods can be used for the location of leaks or the measurement of leakage rates.

The specific test method(s) or technique(s) and Glossary of Terms of the methods in this Article are described in Mandatory Appendices I through X and Nonmandatory Appendix A as follows:

Appendix I — Bubble Test — Direct Pressure Technique

Appendix II — Bubble Test — Vacuum Box Technique

Appendix III — Halogen Diode Detector Probe Test

Appendix IV — Helium Mass Spectrometer Test — Detector Probe Technique

Appendix V — Helium Mass Spectrometer Test — Tracer Probe Technique

Appendix VI — Pressure Change Test

Appendix VII — Glossary of Terms

Appendix VIII — Thermal Conductivity Detector Probe Test

Appendix IX — Helium Mass Spectrometer Test — Hood Technique

Appendix X — Ultrasonic Leak Detector Test

Appendix A — Supplementary Leak Testing Formula Symbols

T-1020 GENERAL

T-1021 Written Procedure Requirements

T-1021.1 Requirements. Leak testing shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in the applicable Appendices, paras. I-1021 through X-1021 and Tables I-1021 through X-1021. The written procedure shall establish a single value, or range of values, for each requirement.

T-1021.2 Modification of Requirements. Article 10 contains test techniques; therefore, there are requirements that cannot be modified by the manufacturer through the demonstration process per T-150. Only those requirements listed in Tables I-1021 through X-1021 may be so modified by demonstration. 04

T-1021.3 Procedure Qualification. When procedure qualification is specified, a change of a requirement in the applicable Appendix Tables I-1021 through X-1021 identified as an *essential* variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a *nonessential* variable does not require requalification of the written procedure. All changes of essential and nonessential elements from those specified within the written procedure shall require revision of, or an addendum to, the written procedure. A06

T-1022 Referencing Code

For the leak testing method(s) or technique(s) specified by the referencing Code, the referencing Code Section shall then be consulted for the following:

(a) personnel qualification/certification

(b) technique(s)/calibration standards

(c) extent of examination

(d) acceptable test sensitivity or leakage rate

(e) report requirements

(f) retention of records

T-1030 EQUIPMENT

T-1031 Gages

(a) Gage Range. When dial indicating and recording pressure gage(s) are used in leak testing, they should

preferably have the dial(s) graduated over a range of approximately double the intended maximum pressure, but in no case shall the range be less than $1\frac{1}{2}$ nor more than four times that pressure. These range limits do not apply to dial indicating and recording vacuum gages. Range requirements for other types of gages given in an applicable Mandatory Appendix shall be as required by that Appendix.

(b) Gage Location. When components are to be pressure/vacuum leak tested, the dial indicating gage(s) shall be connected to the component or to the component from a remote location, with the gage(s) readily visible to the operator controlling the pressure/vacuum throughout the duration of pressurizing, evacuating, testing, and depressurizing or venting of the component. For large vessels or systems where one or more gages are specified or required, a recording type gage is recommended, and it may be substituted for one of the two or more indicating type gages.

(c) When other types of gage(s) are required by an applicable Mandatory Appendix, they may be used in conjunction with or in place of dial indicating or recording type gages.

T-1040 MISCELLANEOUS REQUIREMENTS

T-1041 Cleanliness

The surface areas to be tested shall be free of oil, grease, paint, or other contaminants that might mask a leak. If liquids are used to clean the component or if a hydrostatic or hydropneumatic test is performed before leak testing, the component shall be dry before leak testing.

T-1042 Openings

All openings shall be sealed using plugs, covers, sealing wax, cement, or other suitable material that can be readily and completely removed after completion of the test. Sealing materials shall be tracer gas free.

T-1043 Temperature

The minimum metal temperature for all components during a test shall be as specified in the applicable Mandatory Appendix of this Article or in the referencing Code Section for the hydrostatic, hydropneumatic, or pneumatic test of the pressure component or parts. The minimum or maximum temperature during the test shall not exceed that temperature compatible with the leak testing method or technique used.

T-1044 Pressure/Vacuum (Pressure Limits)

Unless specified in the applicable Mandatory Appendix of this Article or by the referencing Code Section, components that are to be pressure-leak tested shall not be tested at a pressure exceeding 25% of the Design Pressure.

T-1050 PROCEDURE

T-1051 Preliminary Leak Test

Prior to employing a sensitive leak testing method, it may be expedient to perform a preliminary test to detect and eliminate gross leaks. This shall be done in a manner that will not seal or mask leaks during the specified test.

T-1052 Test Sequence

It is recommended that leak testing be performed before hydrostatic or hydropneumatic testing.

T-1060 CALIBRATION

T-1061 Pressure/Vacuum Gages

(a) All dial indicating and recording type gages used shall be calibrated against a standard deadweight tester, a calibrated master gage, or a mercury column, and recalibrated at least once a year, when in use, unless specified differently by the referencing Code Section or Mandatory Appendix. All gages used shall provide results accurate to within the Manufacturer's listed accuracy and shall be recalibrated at any time that there is reason to believe they are in error.

(b) When other than dial indicating or recording type gages are required by an applicable Mandatory Appendix, they shall be calibrated as required by that Mandatory Appendix or referencing Code Section.

T-1062 Temperature Measuring Devices

When temperature measurement is required by the referencing Code Section or Mandatory Appendix, the device(s) shall be calibrated in accordance with the requirements of that Code Section or Mandatory Appendix.

T-1063 Calibration Leak Standards

T-1063.1 Permeation Type Leak Standard. This standard shall be a calibrated permeation type leak through fused glass or quartz. The standard shall have a helium leakage rate in the range of 1×10^{-6} to 1×10^{-10} std cm^3/s. (1×10^{-7} to 1×10^{-11} Pa m^3/s).

T-1063.2 Capillary Type Leak Standard. This standard shall be a calibrated capillary type leak through a tube. The standard shall have a leakage rate equal to or smaller than the required test sensitivity times the actual percent test concentration of the selected tracer gas.

T-1070 TEST

See applicable Mandatory Appendix of this Article.

T-1080 EVALUATION

T-1081 Acceptance Standards

Unless otherwise specified in the referencing Code Section, the acceptance criteria given for each method or technique of that method shall apply. The supplemental leak testing formulas for calculating leakage rates for the method or technique used are stated in the Mandatory Appendices of this Article.

T-1090 DELETED A06

ARTICLE 10
MANDATORY APPENDICES

APPENDIX I — BUBBLE TEST — DIRECT PRESSURE TECHNIQUE

I-1000 INTRODUCTION

I-1010 SCOPE

The objective of the direct pressure technique of bubble leak testing is to locate leaks in a pressurized component by the application of a solution or by immersion in liquid that will form bubbles as leakage gas passes through it.

I-1020 GENERAL

I-1021 Written Procedure Requirements

I-1021.1 Requirements. The requirements of T-1021.1, Table I-1021, and the following as specified in this Article or referencing Code shall apply.

(a) soak time
(b) pressure gage
(c) test pressure
(d) acceptance criteria

I-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table I-1021 shall apply.

I-1030 EQUIPMENT

I-1031 Gases

Unless otherwise specified, the test gas will normally be air; however, inert gases may be used.

NOTE: When inert gas is used, safety aspects of oxygen deficient atmosphere should be considered.

I-1032 Bubble Solution

(a) The bubble forming solution shall produce a film that does not break away from the area to be tested, and the bubbles formed shall not break rapidly due to air drying or low surface tension. Household soap or detergents are not permitted as substitutes for bubble testing solutions.

(b) The bubble forming solution shall be compatible with the temperature of the test conditions.

I-1033 Immersion Bath

(a) Water or another compatible solution shall be used for the bath.

TABLE I-1021
REQUIREMENTS OF A DIRECT PRESSURE BUBBLE LEAK TESTING PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Bubble forming solution (Brand name or type)	X	
Surface temperature[1] (change to outside the range specified in this article or as previously qualified)	X	
Surface preparation technique	X	
Lighting intensity (decrease below that specified in this Article or as previously qualified)	X	
Personnel performance qualification requirements, when required	X	
Solution applicator		X
Pressurizing Gas (air or inert gas)		X
Post testing cleaning technique		X
Personnel qualification requirements		X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

(b) The immersion solution shall be compatible with the temperature of the test conditions.

I-1070 TEST

I-1071 Soak Time

Prior to examination the test pressure shall be held for a minimum of 15 min.

I-1072 Surface Temperature

As a standard technique, the temperature of the surface of the part to be examined shall not be below 40°F (5°C) nor above 125°F (50°C) throughout the examination. Local heating or cooling is permitted provided temperatures remain within the range of 40°F (5°C) to 125°F (50°C) during examination. Where it is impractical to comply with the foregoing temperature limitations, other temperatures may be used provided that the procedure is demonstrated.

I-1073 Application of Solution

The bubble forming solution shall be applied to the surface to be tested by flowing, spraying, or brushing the solution over the examination area. The number of bubbles produced in the solution by application should be minimized to reduce the problem of masking bubbles caused by leakage.

I-1074 Immersion in Bath

The area of interest shall be placed below the surface of the bath in an easily observable position.

I-1075 Lighting and Visual Aids

When performing the test, the requirements of Article 9, T-952 and T-953 shall apply.

I-1076 Indication of Leakage

The presence of continuous bubble growth on the surface of the material indicates leakage through an orifice passage(s) in the region under examination.

I-1077 Post-Test Cleaning

After testing, surface cleaning may be required for product serviceability.

I-1080 EVALUATION

I-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area under test is acceptable when no continuous bubble formation is observed.

I-1082 Repair/Retest

When leakage is observed, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX II — BUBBLE TEST — VACUUM BOX TECHNIQUE

II-1000 INTRODUCTION

II-1010 SCOPE

The objective of the vacuum box technique of bubble leak testing is to locate leaks in a pressure boundary that cannot be directly pressurized. This is accomplished by applying a solution to a local area of the pressure boundary surface and creating a differential pressure across that local area of the boundary causing the formation of bubbles as leakage gas passes through the solution.

II-1020 GENERAL

II-1021 Written Procedure Requirements

II-1021.1 Requirements. The requirements of T-1021.1, Table II-1021, and the following as specified in this Article or referencing Code shall apply:

(a) pressure gage
(b) vacuum test pressure
(c) vacuum retention time
(d) box overlap
(e) acceptance criteria

II-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table II-1021 shall apply.

II-1030 EQUIPMENT

II-1031 Bubble Solution

(a) The bubble forming solution shall produce a film that does not break away from the area to be tested, and the bubbles formed shall not break rapidly due to air drying or low surface tension. The number of bubbles

TABLE II-1021
REQUIREMENTS OF A VACUUM BOX LEAK TESTING PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Bubble forming solution (Brand name or type)	X	
Surface temperature[1] (change to outside the range specified in this article or as previously qualified)	X	
Surface preparation technique	X	
Lighting intensity (decrease below that specified in this Article or as previously qualified)	X	
Personnel performance qualification requirements, when required	X	
Vacuum box (size and shape)		X
Vacuum source		X
Solution applicator		X
Post testing cleaning technique		X
Personnel qualification requirements		X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

contained in the solution should be minimized to reduce the problem of discriminating between existing bubbles and those caused by leakage.

(b) Soaps or detergents designed specifically for cleaning shall not be used for the bubble forming solution.

(c) The bubble forming solution shall be compatible with the temperature conditions of the test.

II-1032 Vacuum Box

The vacuum box used shall be of convenient size [e.g., 6 in. (150 mm) wide by 30 in. (750 mm) long] and contain a window in the side opposite the open bottom. The open bottom edge shall be equipped with a suitable gasket to form a seal against the test surface. Suitable connections, valves, lighting, and gage shall be provided. The gage shall have a range of 0 psi (0 kPa) to 15 psi (100 kPa), or equivalent pressure units such as 0 in. Hg to 30 in. Hg (0 mm Hg to 750 mm Hg). The gage range limit requirements of T-1031(a) do not apply.

II-1033 Vacuum Source

The required vacuum can be developed in the box by any convenient method (e.g., air ejector, vacuum pump, or motor intake manifold). The gage shall register a partial vacuum of at least 2 psi (4 in. Hg) (15 kPa) below atmospheric pressure or the partial vacuum required by the referencing Code Section.

II-1070 TEST

II-1071 Surface Temperature

As a standard technique, the temperature of the surface of the part to be examined shall not be below 40°F (5°C) nor above 125°F (50°C) throughout the examination. Local heating or cooling is permitted provided temperatures remain in the range of 40°F (5°C) to 125°F (50°C) during the examination. Where it is impractical to comply with the foregoing temperature limitations, other temperatures may be used provided that the procedure is demonstrated.

II-1072 Application of Solution

The bubble forming solution shall be applied to the surface to be tested by flowing, spraying, or brushing the solution over the examination area before placement of the vacuum box.

II-1073 Vacuum Box Placement

The vacuum box shall be placed over the solution coated section of the test surface and the box evacuated to the required partial vacuum.

II-1074 Pressure (Vacuum) Retention

The required partial vacuum (differential pressure) shall be maintained for at least 10 sec examination time.

II-1075 Vacuum Box Overlap

An overlap of 2 in. (50 mm) minimum for adjacent placement of the vacuum box shall be used for each subsequent examination.

II-1076 Lighting and Visual Aids

When performing the test, the requirements of Article 9, T-952 and T-953 shall apply.

II-1077 Indication of Leakage

The presence of continuous bubble growth on the surface of the material or weld seam indicates leakage through an orifice passage(s) in the region under examination.

II-1078 Post-Test Cleaning

After testing, cleaning may be required for product serviceability.

II-1080 EVALUATION

II-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area under test is acceptable when no continuous bubble formation is observed.

II-1082 Repair/Retest

When leakage is observed, the location of the leak(s) shall be marked. The vacuum box shall then be vented and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX III — HALOGEN DIODE DETECTOR PROBE TEST

III-1000 INTRODUCTION

The more sophisticated electronic halogen leak detectors have very high sensitivity. These instruments make possible the detection of halogen gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

III-1010 SCOPE

The halogen detector probe test method is a semiquantitative method used to detect and locate leaks, and shall not be considered quantitative.

III-1011 Alkali-Ion Diode (Heated Anode) Halogen Leak Detectors

The alkali-ion diode halogen detector probe instrument uses the principle of a heated platinum element (anode) and an ion collector plate (cathode), where halogen vapor is ionized by the anode, and the ions are collected by the cathode. A current proportional to the rate of ion formation is indicated on a meter.

III-1012 Electron Capture Halogen Leak Detectors

The electron capture halogen detector probe instrument uses the principle of the affinity of certain molecular compounds for low energy free electrons usually produced by ionization of gas flow through an element with a weak radioactive tritium source. When the gas flow contains halides, electron capture occurs causing a reduction in the concentration of halogen ions present as indicated on a meter. Non-electron capturing nitrogen or argon is used as background gas.

III-1020 GENERAL

III-1021 Written Procedure Requirements

III-1021.1 Requirements. The requirements of T-1021.1, Table III-1021, and the following as specified in this Article or referencing Code shall apply.

(a) leak standard
(b) tracer gas
(c) tracer gas concentration
(d) test pressure
(e) soak time
(f) scanning distance
(g) pressure gage
(h) sensitivity verification checks
(i) acceptance criteria

III-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table III-1021 shall apply.

III-1030 EQUIPMENT

III-1031 Tracer Gas

Gases that may be used are shown in Table III-1031.

III-1031.1 For Alkali-Ion Diode. Halogen leak detectors, select a tracer gas from Table III-1031 that will produce the necessary test sensitivity.

III-1031.2 For Electron Capture. Halogen leak detectors, sulfur hexafluoride, SF_6, is the recommended tracer gas.

III-1032 Instrument

An electronic leak detector as described in III-1011 or III-1012 shall be used. Leakage shall be indicated by one or more of the following signaling devices.

TABLE III-1021
REQUIREMENTS OF A HALOGEN DIODE DETECTOR PROBE TESTING PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	
Surface preparation technique	X	
Metal temperature[1] (change to outside the range specified in this Article or as previously qualified)	X	
Personnel performance qualification requirements, when required	X	
Scanning rate (maximum as demonstrated during system calibration)		X
Pressurizing gas (air or an inert gas)		X
Scanning direction		X
Signaling device		X
Post testing cleaning technique		X
Personnel qualification requirements		X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

TABLE III-1031
TRACER GASES

Commercial Designation	Chemical Designation	Chemical Symbol
Refrigerant-11	Trichloromonofluoromethane	CCl_3F
Refrigerant-12	Dichlorodifluoromethane	CCl_2F_2
Refrigerant-21	Dichloromonofluoromethane	$CHCl_2F$
Refrigerant-22	Chlorodifluoromethane	$CHClF_2$
Refrigerant-114	Dichlorotetrafluoroethane	$C_2Cl_2F_4$
Refrigerant-134a	Tetrafluoroethane	$C_2H_2F_4$
Methylene Chloride	Dichloromethane	CH_2Cl_2
Sulfur Hexafluoride	Sulfur Hexafluoride	SF_6

(a) Meter — a meter on the test instrument, or a probe, or both.

(b) Audio Devices — a speaker or set of headphones that emits audible indications.

(c) Indicator Light — a visible indicator light.

III-1033 Capillary Calibration Leak Standard

A capillary type leak standard per T-1063.2 using 100% tracer gas as selected per III-1031.

III-1060 CALIBRATION

III-1061 Standard Leak Size

The maximum leakage rate Q for the leak standard described in III-1033 containing 100% tracer concentration for use in III-1063 shall be calculated as follows:

$$Q = Q_s \frac{\%TG}{100}$$

where Q_s is 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s), unless specified otherwise by the referencing Code Section, and %TG is the concentration of the tracer gas (in %) that is to be used for the test (See III-1072).

III-1062 Warm Up

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

III-1063 Scanning Rate

The instrument shall be calibrated by passing the probe tip across the orifice of the leak standard in III-1061. The probe tip shall be kept within $\frac{1}{8}$ in. (3 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted or the audible alarm or indicator light set for this scanning rate.

III-1064 Detection Time

The time required to detect leakage from the leak standard is the detection time and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

III-1065 Frequency and Sensitivity

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be determined before and after testing and at intervals of not more than

4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or indicator light indicates that the detector cannot detect leakage from the leak standard of III-1061, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

III-1070 TEST

III-1071 Location of Test

(a) The test area shall be free of contaminants that could interfere with the test or give erroneous results.

(b) The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

III-1072 Concentration of Tracer Gas

The concentration of the tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

III-1073 Soak Time

Prior to examination, the test pressure shall be held a minimum of 30 min. When demonstrated, the minimum allowable soak time may be less than that specified above due to the immediate dispersion of the halogen gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with halogen gas.

III-1074 Scanning Distance

After the required soak time per III-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $\frac{1}{8}$ in. (3 mm) of the test surface during scanning. If a shorter distance is used during calibration, then that distance shall not be exceeded during the examination scanning.

III-1075 Scanning Rate

The maximum scanning rate shall be as determined in III-1063.

III-1076 Scanning Direction

The examination scan should commence in the uppermost portion of the system being leak tested while progressively scanning downward.

III-1077 Leakage Detection

Leakage shall be indicated and detected according to III-1032.

III-1078 Application

The following are two examples of applications that may be used (note that other types of applications may be used).

III-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube end and held for the time period established by demonstration. The examination scan should commence in the uppermost portion of the tubesheet tube rows while progressively scanning downward.

III-1078.2 Tube-to-Tubesheet Joint Examination. Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

III-1080 EVALUATION

III-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s).

III-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX IV — HELIUM MASS SPECTROMETER TEST — DETECTOR PROBE TECHNIQUE

IV-1000 INTRODUCTION

IV-1010 SCOPE

This technique describes the use of the helium mass spectrometer to detect minute traces of helium gas in

TABLE IV-1021
REQUIREMENTS OF A HELIUM MASS SPECTROMETER DETECTOR PROBE TESTING PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	
Detector Probe manufacturer and model	X	
Surface preparation technique	X	
Metal temperature[1] (change to outside the range specified in this Article or as previously qualified)	X	
Personnel performance qualification requirements, when required	X	
Pressurizing gas (air or inert gas)		X
Scanning rate (maximum as demonstrated during system calibration)		X
Signaling device		X
Scanning direction		X
Post testing cleaning technique		X
Personnel qualification requirements		X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

pressurized components. The high sensitivity of this leak detector makes possible the detection of helium gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures, or the determination of the presence of helium in any gaseous mixture. The detector probe is a semiquantitative technique used to detect and locate leaks, and shall not be considered quantitative.

IV-1020 GENERAL

IV-1021 Written Procedure Requirements

IV-1021.1 Requirements. The requirements of T-1021.1, Table IV-1021, and the following as specified in this Article or referencing Code shall apply.

(a) instrument leak standard
(b) system leak standard
(c) tracer gas
(d) tracer gas concentration
(e) test pressure
(f) soak time
(g) scanning distance
(h) pressure gage
(i) sensitivity verification checks
(j) acceptance criteria

IV-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table IV-1021 shall apply.

IV-1030 EQUIPMENT

IV-1031 Instrument

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by one or more of the following signaling devices.

(a) Meter — a meter on, or attached to, the test instrument.

(b) Audio Devices — a speaker or set of headphones that emits audible indications.

(c) Indicator Light — a visible indicator light.

IV-1032 Auxiliary Equipment

(a) Transformer. A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) Detector Probe. All areas to be examined shall be scanned for leaks using a detector probe (sniffer) connected to the instrument through flexible tubing or a hose. To reduce instrument response and clean up time, the tubing or hose length shall be less than 15 ft (4.5 m), unless the test setup is specifically designed to attain the reduced response and clean up time for longer tubing or hose lengths.

IV-1033 Calibration Leak Standards

Calibration leak standards may be either a permeation or capillary type standard per T-1063.1 and T-1063.2. The type of leak standard used shall be established by the instrument or system sensitivity requirement, or as specified by the referencing Code Section.

IV-1060 CALIBRATION

IV-1061 Instrument Calibration

IV-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the calibrated leak standard.

IV-1061.2 Calibration. Calibrate the helium mass spectrometer per the instruments manufacturer's operation and maintenance manual, using a permeation type leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The instrument shall have a sensitivity of at least 1×10^{-9} std cm^3/s (1×10^{-10} Pa m^3/s) for helium.

IV-1062 System Calibration

IV-1062.1 Standard Leak Size. The maximum leakage rate Q for the leak standard described in IV-1033, containing 100% helium concentration for use in IV-1062.2, shall be calculated as follows:

$$Q = Q_s \frac{\%TG}{100}$$

where Q_s is 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s), unless specified otherwise by the referencing Code Section, and *%TG* is the concentration of the tracer gas (in %) that is to be used for the test (See IV-1072).

IV-1062.2 Scanning Rate. After connecting the detector probe to the instrument, the system shall be calibrated by passing the detector probe tip across the orifice of the leak standard in IV-1062.1. The probe tip shall be kept within $\frac{1}{8}$ in. (3 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted or the audible alarm or indicator light set for this scanning rate.

IV-1062.3 Detection Time. The time required to detect leakage from the leak standard is the detection time, and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

IV-1062.4 Frequency and Sensitivity. Unless otherwise specified by the referencing Code Section, the system sensitivity shall be determined before and after testing and at intervals of not more than 4 hr during the test. During any calibration check, if the meter deflection, audible alarm, or visible light indicates that the system cannot detect leakage per IV-1062.2, the system, and if necessary, the instrument, shall be recalibrated and all areas tested after the last satisfactory calibration check shall be retested.

IV-1070 TEST

IV-1071 Location of Test

The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

IV-1072 Concentration of Tracer Gas

The concentration of the helium tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

IV-1073 Soak Time

Prior to testing, the test pressure shall be held a minimum of 30 min. The minimum allowable soak time may be less than that specified above due to the immediate dispersion of the helium gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with helium gas.

IV-1074 Scanning Distance

After the required soak time per IV-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within $\frac{1}{8}$ in. (3 mm) of the test surface during scanning. If a shorter distance is used during system calibration, then that distance shall not be exceeded during test scanning.

IV-1075 Scanning Rate

The maximum scanning rate shall be as determined in IV-1062.2.

IV-1076 Scanning Direction

The examination scan should commence in the lowermost portion of the system being tested while progressively scanning upward.

IV-1077 Leakage Detection

Leakage shall be indicated and detected according to IV-1031.

IV-1078 Application

The following are two examples of applications that may be used (note that other types of applications may be used).

IV-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube end and held for the time period established by demonstration. The examination scan should commence in the lowermost portion of the tubesheet tube rows while progressively scanning upward.

IV-1078.2 Tube-to-Tubesheet Joint Examination. Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

IV-1080 EVALUATION

IV-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-4} std cm^3/s (1×10^{-5} Pa m^3/s).

IV-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX V — HELIUM MASS SPECTROMETER TEST — TRACER PROBE TECHNIQUE

V-1010 SCOPE

This technique describes the use of the helium mass spectrometer to detect minute traces of helium gas in evacuated components.

The high sensitivity of this leak detector, when tracer probe testing, makes possible the detection and location of helium gas flow from the higher pressure side of very small openings through the evacuated envelope or barrier separating the two regions at different pressures. This is a semiquantitative technique and shall not be considered quantitative.

V-1020 GENERAL

V-1021 Written Procedure Requirements

V-1021.1 Requirements. The requirements of T-1021.1, Table V-1021, and the following as specified in this Article or referencing Code shall apply.

(a) instrument leak standard
(b) system leak standard
(c) tracer gas
(d) vacuum test pressure
(e) vacuum gaging
(f) soak time
(g) scanning distance
(h) sensitivity verification checks
(i) acceptance criteria

V-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table V-1021 shall apply.

V-1030 EQUIPMENT

V-1031 Instrument

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by one or more of the following signaling devices.

(a) Meter — a meter on or attached to the test instrument.

(b) Audio Devices — a speaker or set of headphones that emits audible indications.

(c) Indicator Light — a visible indicator light.

V-1032 Auxiliary Equipment

(a) Transformer. A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) Auxiliary Pump System. When the size of the test system necessitates the use of an auxiliary vacuum pump system, the ultimate absolute pressure and pump speed capability of that system shall be sufficient to attain required test sensitivity and response time.

(c) Manifold. A system of pipes and valves with proper connections for the instrument gages, auxiliary pump, calibration leak standard, and test component.

(d) Tracer Probe. Tubing connected to a source of 100% helium with a valved fine opening at the other end for directing a fine stream of helium gas.

(e) Vacuum Gage(s). The range of vacuum gage(s) capable of measuring the absolute pressure at which the evacuated system is being tested. The gage(s) for large systems shall be located on the system as far as possible from the inlet to the pump system.

TABLE V-1021
REQUIREMENTS OF A HELIUM MASS SPECTROMETER TRACER PROBE TESTING PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	
Surface preparation technique	X	
Metal temperature[1] (change to outside the range specified in this Article or as previously qualified)	X	
Tracer probe manufacturer and model	X	
Personnel performance qualification requirements, when required	X	
Tracer probe flow rate (minimum demonstrated during system calibration)		X
Scanning rate (maximum as demonstrated during system calibration)		X
Signaling device		X
Scanning direction		X
Vacuum pumping system		X
Post testing cleaning technique		X
Personnel qualification requirements		X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

V-1033 Calibration Leak Standard

A capillary type leak standard per T-1063.2 with a maximum helium leakage rate of 1×10^{-5} std cm^3/s (1×10^{-6} Pa m^3/s) shall be used unless otherwise specified by the referencing Code Section.

V-1060 CALIBRATION

V-1061 Instrument Calibration

V-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the calibration leak standard.

V-1061.2 Calibration. Calibrate the helium mass spectrometer per the instruments manufacturer's operation and maintenance manual, using a permeation type leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The instrument shall have a sensitivity of at least 1×10^{-9} std cm^3/s (1×10^{-10} Pa m^3/s) for helium.

V-1062 System Calibration

V-1062.1 Standard Leak Size. The calibrated leak standard, as stated in V-1033, shall be attached to the component as far as possible from the instrument connection to the component. The leak standard shall remain open during system calibration.

V-1062.2 Scanning Rate. With the component evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system, the system shall be calibrated for the test by passing the tracer probe tip across the orifice of the leak standard. The probe tip shall be kept within $\frac{1}{4}$ in. (6 mm) of the orifice of the leak standard. For a known flow rate from the tracer probe of 100% helium, the scanning rate shall not exceed that which can detect leakage through the calibration leak standard into the test system.

V-1062.3 Detection Time. The time required to detect leakage from the leak standard is the detection time, and it should be observed during system calibration. It is desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

V-1062.4 Frequency and Sensitivity. Unless otherwise specified by the referencing Code Section, the system sensitivity shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or visible light indicates that the system cannot detect leakage per V-1062.2, the system, and if necessary, the instrument, shall be recalibrated and all areas tested after the last satisfactory calibration check shall be retested.

V-1070 TEST

V-1071 Scanning Rate

The maximum scanning rate shall be as determined in V-1062.2.

V-1072 Scanning Direction

The examination scan should commence in the uppermost portion of the system being tested while progressively scanning downward.

V-1073 Scanning Distance

The tracer probe tip shall be kept within $\frac{1}{4}$ in. (6 mm) of the test surface during scanning. If a shorter distance is used during system calibration, then that distance shall not be exceeded during the examination scanning.

V-1074 Leakage Detection

Leakage shall be indicated and detected according to V-1031.

V-1075 Flow Rate

The minimum flow rate shall be as set in V-1062.2.

V-1080 EVALUATION

V-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-5} std cm^3/s (1×10^{-6} Pa m^3/s).

V-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be vented, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX VI — PRESSURE CHANGE TEST

VI-1010 SCOPE

This test method describes the techniques for determining the leakage rate of the boundaries of a closed component or system at a specific pressure or vacuum. Pressure hold, absolute pressure, maintenance of pressure, pressure loss, pressure decay, pressure rise, and vacuum retention are examples of techniques that may be used whenever pressure change testing is specified as a means of determining leakage rates. The tests specify a maximum allowable change in either pressure per unit of time, percentage volume, or mass change per unit of time.

VI-1020 GENERAL

VI-1021 Written Procedure Requirements

VI-1021.1 Requirements. The requirements of T-1021.1, Table VI-1021, and the following as specified in this Article or referencing Code shall apply.

(a) test/vacuum test pressure
(b) soak time
(c) test duration
(d) recording interval
(e) acceptance criteria

VI-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table VI-1021 shall apply.

VI-1030 EQUIPMENT

VI-1031 Pressure Measuring Instruments

(a) Gage Range. Dial indicating and recording type gages shall meet the requirements of T-1031(a). Liquid manometers or quartz Bourdon tube gages may be used over their entire range.

(b) Gage Location. The location of the gage(s) shall be that stated in T-1031(b).

(c) Types of Gages. Regular or absolute gages may be used in pressure change testing. When greater accuracy is required, quartz Bourdon tube gages or liquid manometers may be used. The gage(s) used shall have an accuracy, resolution, and repeatability compatible with the acceptance criteria.

VI-1032 Temperature Measuring Instruments

Dry bulb or dew point temperature measuring instruments, when used, shall have accuracy, repeatability, and resolution compatible with the leakage rate acceptance criteria.

VI-1060 CALIBRATION

VI-1061 Pressure Measuring Instruments

All dial indicating, recording, and quartz Bourdon tube gages shall be calibrated per T-1061(b). The scale of liquid manometers shall be calibrated against standards that have known relationships to national standards, where such standards exist.

VI-1062 Temperature Measuring Instruments

Calibration for dry bulb and dew point temperature measuring instruments shall be against standards that

TABLE VI-1021
REQUIREMENTS OF A PRESSURE CHANGE TESTING PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Pressure or vacuum gage manufacturer and model	X	
Temperature measuring instrument manufacturer and model, when applicable	X	
Surface preparation technique	X	
Metal temperature[1] (change to outside the range specified in this Article or as previously qualified)	X	
Personnel performance qualification requirements, when required	X	
Vacuum pumping system, when applicable		X
Post testing cleaning technique		X
Personnel qualification requirements		X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

have known relationships to national standards, where such standards exist.

VI-1070 TEST

VI-1071 Pressure Application

Components that are to be tested above atmospheric pressure shall be pressurized per T-1044.

VI-1072 Vacuum Application

Components that are to be tested under vacuum shall be evacuated to at least 2 psi (4 in. Hg) (15 kPa) below atmospheric pressure or as required by the referencing Code Section.

VI-1073 Test Duration

The test pressure (or vacuum) shall be held for the duration specified by the referencing Code Section or, if not specified, it shall be sufficient to establish the leakage rate of the component system within the accuracy or confidence limits required by the referencing Code Section. For very small components or systems, a test duration in terms of minutes may be sufficient. For large components or systems, where temperature and water vapor corrections are necessary, a test duration in terms of many hours may be required.

VI-1074 Small Pressurized Systems

For temperature stabilization of very small pressurized systems, such as gasket interspaces, where only system (metal) temperature can be measured, at least 15 min shall elapse after completion of pressurization and before starting the test.

VI-1075 Large Pressurized Systems

For temperature stabilization of large pressurized systems where the internal gas temperature is measured after completion of pressurization, it shall be determined that the temperature of the internal gas has stabilized before starting the test.

VI-1076 Start of Test

At the start of the test, initial temperature and pressure (or vacuum) readings shall be taken and thereafter at regular intervals, not to exceed 60 min, until the end of the specified test duration.

VI-1077 Essential Variables

(a) When it is required to compensate for barometric pressure variations, measurement of the test pressure shall be made with either an absolute pressure gage or a regular pressure gage and a barometer.

(b) When it is required by the referencing Code Section, or when the water vapor pressure variation can significantly affect the test results, the internal dew point temperature or relative humidity shall be measured.

VI-1080 EVALUATION

VI-1081 Acceptable Test

When the pressure change or leakage rate is equal to or less than that specified by the referencing Code Section, the test is acceptable.

VI-1082 Rejectable Test

When the pressure change or leakage rate exceeds that specified by the referencing Code Section, the results of

the test are unsatisfactory. Leak(s) may be located by other methods described in the Mandatory Appendices. After the cause of the excessive pressure change or leakage rate has been determined and repaired in accordance with the referencing Code Section, the original test shall be repeated.

NOTE: For more information regarding this method of testing refer to the following:

(a) 10 CFR 50, Appendix J, *Primary Containment Leakage Testing for Water Cooled Power Reactors.*

(b) ANSI/ANS 56.8-1981, *American National Standard Containment System Leakage Testing Requirements,* published by the American Nuclear Society.

APPENDIX VII — GLOSSARY OF TERMS FOR LEAK TESTING

VII-1010 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms which appear in Article 10, Leak Testing.

VII-1020 GENERAL

(a) ASTM E 1316, Standard Terminology for Nondestructive Examinations, has been adopted by the Committee as SE-1316.

(b) SE-1316 Section 8 provides the definitions of terms listed in (e).

(c) For general terms such as *Discontinuity, Evaluation, Flaw, Indication, Inspection,* etc., refer to Article 1, Mandatory Appendix I.

(d) The following SE-1316 terms are used in conjunction with this Article: *absolute pressure; background signal; gage pressure; gas; halogen; halogen leak detector; hood test; leak; leakage rate; leak testing; mass spectrometer; mass spectrometer leak detector; sampling probe; standard leak; tracer gas; vacuum.*

(e) The following Code terms, which are in addition to SE-1316, and are Code specific, are used in conjunction with this Article.

background reading — see *background signal* in (d)

calibration leak standard — see *standard leak* in (d)

detector probe — see *sampling probe* in (d)

dew point temperature — that temperature at which the gas in a system would be capable of holding no more water vapor and condensation in the form of dew would occur

dry bulb temperature — the ambient temperature of the gas in a system

halogen diode detector — see *halogen leak detector* in (d)

helium mass spectrometer — see *mass spectrometer* and *mass spectrometer leak detector* in (d)

hood technique — see *hood test* in (d)

immersion bath — a low surface tension liquid into which a gas containing enclosure is submerged to detect leakage which forms at the site or sites of a leak or leaks

immersion solution — see *immersion bath*

inert gas — a gas that resists combining with other substances. Examples are helium, neon, and argon.

instrument calibration — introduction of a known size standard leak into an isolated leak detector for the purpose of determining the smallest size leakage rate of a particular gas at a specific pressure and temperature that the leak detector is capable of indicating for a particular division on the leak indicator scale

leakage — the fluid, either liquid or gas, flowing through a leak and expressed in units of mass flow; i.e., pressure and volume per time

leak standard — see *standard leak* in (d)

quartz Bourdon tube gage — this high accuracy gage is a servonulling differential pressure measuring electronic instrument. The pressure transducing element is a one piece fused quartz Bourdon element.

regular pressure — see *gage pressure* in (d)

sensitivity — the size of the smallest leakage rate that can be unambiguously detected by the leak testing instrument, method, or technique being used

soak time — the elapsed time between when the desired differential pressure is attained on a system and the time when the test technique is performed to detect leakage or measure leakage rate

standard dead weight tester — a device for hydraulically balancing the pressure on a known high accuracy weight against the reading on a pressure gage for the purpose of calibrating the gage

system calibration — introduction of a known size standard leak into a test system with a leak detector for the purpose of determining the smallest size leakage rate of a particular gas at a specific pressure and temperature that the leak detector as part of the test system is capable of indicating for a particular division on the leak indicator scale

thermal conductivity detector — a leak detector that responds to differences in the thermal conductivity of a sampled gas and the gas used to zero it (i.e., background atmosphere)

vacuum box — a device used to obtain a pressure differential across a weld that cannot be directly pressurized. It contains a large viewing window, special easy seating and sealing gasket, gage, and a valved connection

TABLE VIII-1021
REQUIREMENTS OF A THERMAL CONDUCTIVITY DETECTOR PROBE TESTING PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	
Surface preparation technique	X	
Metal temperature[1] (change to outside the range specified in this Article or as previously qualified)	X	
Tracer gas	X	
Personnel performance qualification requirements, when required	X	
Scanning rate (maximum demonstrated during system calibration)		X
Signaling device		X
Scanning direction		X
Post testing cleaning technique		X
Personnel qualification requirements		X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

for an air ejector, vacuum pump, or intake manifold

water vapor — gaseous form of water in a system

APPENDIX VIII — THERMAL CONDUCTIVITY DETECTOR PROBE TEST

VIII-1000 INTRODUCTION

These instruments make possible the detection of a tracer gas flow from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

VIII-1010 SCOPE

The thermal conductivity detector probe test method is a semiquantitative method used to detect and locate leaks, and shall not be considered quantitative.

VIII-1011 Thermal Conductivity Leak Detectors

The thermal conductivity detector probe instrument uses the principle that the thermal conductivity of a gas or gas mixture changes with any change in the concentration(s) of the gas or gas mixture (i.e., the introduction of a tracer gas in the area of a leak).

VIII-1020 GENERAL

VIII-1021 Written Procedure Requirements

VIII-1021.1 Requirements. The requirements of T-1021.1, Table VIII-1021, and the following as specified in this Article or referencing Code shall apply.

(a) leak standard
(b) tracer gas concentration
(c) test pressure
(d) soak time
(e) scanning distance
(f) pressure gage
(g) sensitivity verification checks
(h) acceptance criteria

VIII-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table VIII-1021 shall apply.

VIII-1030 EQUIPMENT

VIII-1031 Tracer Gas

In principle, any gas having a thermal conductivity different from air can be used as a tracer gas. The sensitivity achievable depends on the relative differences of the thermal conductivity of the gases [i.e., background air (air used to zero the instrument) and the sampled air (air containing the tracer gas) in the area of a leak]. Table VIII-1031 lists some of the typical tracer gases used. The tracer gas to be used shall be selected based on the required test sensitivity.

VIII-1032 Instrument

An electronic leak detector as described in VIII-1011 shall be used. Leakage shall be indicated by one or more of the following signaling devices:

(a) Meter. A meter on the test instrument, or a probe, or both.

TABLE VIII-1031
TRACER GASES

Designation	Chemical Designation	Chemical Symbol
...	Helium	He
...	Argon	Ar
...	Carbon Dioxide	CO_2
Refrigerant-11	Trichloromonofluoromethane	CCl_3F
Refrigerant-12	Dichlorodifluoromethane	CCl_2F_2
Refrigerant-21	Dichloromonofluoromethane	$CHCl_2F$
Refrigerant-22	Chlorodifluoromethane	$CHClF_2$
Refrigerant-114	Dichlorotetrafluoroethane	$C_2Cl_2F_4$
Refrigerant-134a	Tetrafluoroethane	$C_2H_2F_4$
Methylene Chloride	Dichloromethane	CH_2Cl_2
Sulfur Hexafluoride	Sulfur Hexafluoride	SF_6

(b) Audio Devices. A speaker or sets of headphones that emit(s) audible indications.

(c) Indicator Light. A visible indicator light.

VIII-1033 Capillary Calibration Leak Standard

A capillary type leak standard per T-1063.2 using 100% tracer gas as selected per VIII-1031.

VIII-1060 CALIBRATION

VIII-1061 Standard Leak Size

The maximum leakage rate Q for the leak standard described in VIII-1033 containing 100% tracer concentration for use in VIII-1063 shall be calculated as follows:

$$Q = Q_s \frac{\%\ \mathrm{TG}}{100}$$

where Q_s [in std cm^3/s (Pa m^3/s)] is the required test sensitivity and *%TG* is the concentration of the tracer gas (in %) that is to be used for the test. See VIII-1072.

VIII-1062 Warm-up

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

VIII-1063 Scanning Rate

The detector shall be calibrated by passing the probe tip across the orifice of the leak standard in VIII-1061. The probe tip shall be kept within ½ in. (13 mm) of the orifice of the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard. The meter deflection shall be noted or the audible alarm or indicator light set for this scanning rate.

VIII-1064 Detection Time

The time required to detect leakage from the leak standard is the detection time and it should be observed during system calibration. It is usually desirable to keep this time as short as possible to reduce the time required to pinpoint detected leakage.

VIII-1065 Frequency and Sensitivity

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be determined before and after testing and at intervals of not more than 4 hr during testing. During any calibration check, if the meter deflection, audible alarm, or indicator light indicate that the detector cannot detect leakage per VIII-1063, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

VIII-1070 TEST

VIII-1071 Location of Test

(a) The test area shall be free of contaminants that could interfere with the test or give erroneous results.

(b) The component to be tested shall, if possible, be protected from drafts or located in an area where drafts will not reduce the required sensitivity of the test.

VIII-1072 Concentration of Tracer Gas

The concentration of the tracer gas shall be at least 10% by volume at the test pressure, unless otherwise specified by the referencing Code Section.

VIII-1073 Soak Times

Prior to examination, the test pressure shall be held a minimum of 30 min. When demonstrated, the minimum allowable soak time may be less than that specified above due to the immediate dispersion of the tracer gas when:

(a) a special temporary device (such as a leech box) is used on open components to test short segments;

(b) components are partially evacuated prior to initial pressurization with tracer gas.

VIII-1074 Scanning Distance

After the required soak time per VIII-1073, the detector probe tip shall be passed over the test surface. The probe tip shall be kept within ½ in. (13 mm) of the test surface during scanning. If a shorter distance is used during calibration, then that distance shall not be exceeded during the examination scanning.

VIII-1075 Scanning Rate

The maximum scanning rate shall be as determined in VIII-1063.

VIII-1076 Scanning Direction

For tracer gases that are lighter than air, the examination scan should commence in the lowermost portion of the system being tested while progressively scanning upward. For tracer gases that are heavier than air, the examination scan should commence in the uppermost portion of the system being tested while progressively scanning downward.

VIII-1077 Leakage Detection

Leakage shall be indicated and detected according to VIII-1032.

VIII-1078 Application

The following are two examples of applications that may be used (note that other types of applications may be used).

VIII-1078.1 Tube Examination. To detect leakage through the tube walls when testing a tubular heat exchanger, the detector probe tip should be inserted into each tube and held for the time period established by demonstration.

VIII-1078.2 Tube-to-Tubesheet Joint Examination. Tube-to-tubesheet joints may be tested by the encapsulator method. The encapsulator may be a funnel type with the small end attached to the probe tip end and the large end placed over the tube-to-tubesheet joint. If the encapsulator is used, the detection time is determined by placing the encapsulator over the orifice on the leak standard and noting the time required for an indicated instrument response.

VIII-1080 EVALUATION

VIII-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the maximum leakage rate Q, determined per VIII-1061.

VIII-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX IX
HELIUM MASS SPECTROMETER TEST — HOOD TECHNIQUE

IX-1010 SCOPE

This technique describes the use of the helium mass spectrometer to respectively detect and measure minute traces of helium gas in evacuated components.

The high sensitivity of this leak detector, when hood testing, makes possible the detection and measurement of total helium gas flow from the higher pressure side of all hooded, very small openings through the evacuated envelope or barrier that separates the two regions at different pressures. This is a quantitative measurement technique.

IX-1020 GENERAL

IX-1021 Written Procedure Requirements

IX-1021.1 Requirements. The requirements of T-1021.1, Table IX-1021, and the following as specified in this Article or referencing Code shall apply.

(a) instrument leak standard
(b) system leak standard
(c) vacuum gaging
(d) acceptance criteria

IX-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table IX-1021 shall apply.

IX-1030 EQUIPMENT

IX-1031 Instrument

A helium mass spectrometer leak detector capable of sensing and measuring minute traces of helium shall be used. Leakage shall be indicated by a meter on or attached to the test instrument.

IX-1032 Auxiliary Equipment

(a) Transformer. A constant voltage transformer shall be used in conjunction with the instrument when line voltage is subject to variations.

(b) Auxiliary Pump System. When the size of the test system necessitates the use of an auxiliary vacuum pump system, the ultimate absolute pressure and pump speed

TABLE IX-1021
REQUIREMENTS OF A HELIUM MASS SPECTROMETER HOOD TESTING PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	
Surface preparation technique	X	
Metal temperature[1] (change to outside the range specified in this article or as previously qualified)	X	
Technique of establishing minimum concentration of tracer gas in the hood	X	
Personnel performance qualification requirements, when required	X	
Hood materials		X
Vacuum pumping system		X
Post testing cleaning technique		X
Personnel qualification requirements		X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

capability of that system shall be sufficient to attain required test sensitivity and response time.

(c) Manifold. A system of pipes and valves with proper connections for the instrument gages, auxiliary pump, calibration leak standard, and test component.

(d) Hood. Any suitable envelope or container, such as a plastic bag, with a through aperture for the manifold.

(e) Vacuum Gage(s). The range of vacuum gage(s) capable of measuring the absolute pressure at which the evacuated system is being tested. The gage(s) for large systems shall be located on the system as far as possible from the inlet to the pump system.

IX-1033 Calibration Leak Standard

A permeation type leak standard per T-1063.1 with a maximum helium leakage rate of 1×10^{-6} std cm^3/s (1×10^{-7} Pa m^3/s) shall be used, unless specified otherwise by the referencing Code Section.

IX-1050 TECHNIQUE

IX-1051 Permeation

When systems with long response times (i.e., low helium mass spectrometer throughput) are to be tested, helium permeation through nonmetallic seals can lead to false results. In cases like this, it is recommended, if possible, to locally hood test such seals or exclude them from the hood if the seals are not required to be tested.

IX-1052 Repetitive or Similar Tests

For repetitive tests or where the test time is known from previous similar tests, the preliminary calibration, per IX-1062.4, may be omitted.

IX-1060 CALIBRATION

IX-1061 Instrument Calibration

IX-1061.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibrating with the leak standard.

IX-1061.2 Calibration. Calibrate the helium mass spectrometer per the instrument manufacturer's operation and maintenance manual using a permeation type leak standard as stated in T-1063.1 to establish that the instrument is at optimum or adequate sensitivity. The instrument shall have sensitivity of at least 1×10^{-9} std cm^3/s (1×10^{-10} Pa m^3/s) for helium.

IX-1062 System Calibration

IX-1062.1 Standard Leak Size. A calibrated leak *CL* standard as per T-1063.1 with 100% helium shall be attached, where feasible, to the component as far as possible from the instrument connection to the component.

IX-1062.2 Response Time. With the component evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system, the system shall be calibrated by opening the leak standard to the system. The leak standard shall remain open until the instrument signal becomes stable.

The time shall be recorded when the leak standard is first opened to the component and again when the increase in output signal becomes stable. The elapsed time between the two readings is the response time. The stable instrument reading shall be noted and recorded as M_1 in divisions.

IX-1062.3 Background Reading. [1] Background M_2 in divisions is established after determining response time. The leak standard shall be closed to the system and the instrument reading shall be recorded when it becomes stable.

IX-1062.4 Preliminary Calibration. The preliminary system sensitivity shall be calculated as follows:

$$S_1 = \frac{CL}{M_1 - M_2} = \text{std cm}^3/\text{s/div (Pa m}^3/\text{s/div)}$$

The calibration shall be repeated when there is any change in the leak detector setup (e.g., a change in the portion of helium bypassed to the auxiliary pump, if used) or any change in the leak standard. The leak standard shall be isolated from the system upon completing the preliminary system sensitivity calibration.

IX-1062.5 Final Calibration. Upon completing the test of the system per IX-1071.4, and with the component still under the hood, the leak standard shall be again opened into the system being tested. The increase in instrument output shall be noted and recorded as M_4 in divisions and used in calculating the final system sensitivity as follows:

$$S_2 = \frac{CL}{M_4 - M_3} = \text{std cm}^3/\text{s/div (Pa m}^3/\text{s/div)}$$

If the final system sensitivity S_2 has decreased below the preliminary system sensitivity S_1 by more than 35%, the instrument shall be cleaned and/or repaired, recalibrated, and the component retested.

IX-1070 TEST

IX-1071 Standard Technique

IX-1071.1 Hood. For a single wall component or part, the hood (envelope) container may be made of a material such as plastic.

IX-1071.2 Filling of Hood with Tracer Gas. After completing preliminary calibration per IX-1062.4, the space between the component outer surface and the hood shall be filled with helium.

IX-1071.3 Estimating or Determining Hood Tracer Gas Concentration. The tracer gas concentration in the hood enclosure shall be determined or estimated.

IX-1071.4 Test Duration. After filling the hood with helium, the instrument output M_3 in divisions shall be noted and recorded after waiting for a test time equal to the response time determined in IX-1062.2 or, if the output signal has not become stable, until the output signal stabilizes.

IX-1071.5 System Measured Leakage Rate. After completing final calibration per IX-1062.5, the system leakage rate shall be determined as follows:

(a) For tests where no change in output signal occurs (i.e., $M_2 = M_3$), the system leakage rate shall be reported as being "below the detectable range of the system" and the item under test passes.

(b) For tests where the output signal (M_3) remains on scale, the leakage rate shall be determined as follows:

$$Q = \frac{S_2 (M_3 - M_2) \times 100}{\%\text{TG}} \text{ std cm}^3/\text{s (Pa m}^3/\text{s)}$$

where *%TG* is the concentration of the tracer gas (in %) in the hood. See IX-1071.3.

(c) For tests where the output signal (M_3) exceeds the detectable range of the system (i.e., output signal is off scale), the system leakage rate shall be reported as being "greater than the detectable range of the system" and the item under test fails.

IX-1072 Alternative Technique

IX-1072.1 System Correction Factor. For helium mass spectrometer leak indicator meters in leakage rate units, a System Correction Factor (SCF) may be utilized if it is desired to utilize the actual indicator meter leakage rate units in lieu of converting the readings to divisions [e.g., the values of M_1, M_2, M_3, and M_4 are directly read from the helium mass spectrometer in std cm^3/s (Pa m^3/s)].

IX-1072.2 Alternative Formulas. The following formulas shall be used in lieu of those described in IX-1062:

(a) Preliminary Calibration (per IX-1062.4). The preliminary system correction factor (PSCF) shall be calculated as follows:

$$PSCF = CL / (M_1 - M_2)$$

(b) Final Calibration (per IX-1062.5). The final system correction factor (FSCF) shall be calculated as follows:

$$FSCF = CL / (M_4 - M_3)$$

If the FSCF has decreased below the PSCF by more than 35%, the instrument shall be cleaned and/or repaired, recalibrated, and the component retested.

(c) System Measured Leakage Rate (per IX-1071.5). The system leakage rate shall be determined as follows:

$$Q = \frac{[FSCF (M_3 - M_2)] \times 100}{\%\text{TG}} \text{ std cm}^3/\text{s (Pa m}^3/\text{s)}$$

[1] System background noise. For definition of symbols, see Nonmandatory Appendix A.

IX-1080 EVALUATION

Unless otherwise specified by the referencing Code Section, the component tested is acceptable when the measured leakage rate Q is equal to or less than 1×10^{-6} std cm^3/s (1×10^{-7} Pa m^3/s) of helium.

IX-1081 Leakage

When the leakage rate exceeds the permissible value, all welds or other suspected areas shall be retested using a tracer probe technique. All leaks shall be marked and temporarily sealed to permit completion of the tracer probe retest. The temporary seals shall be of a type which can be readily and completely removed after testing has been completed.

IX-1082 Repair/Retest

The component shall then be vented and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

APPENDIX X
ULTRASONIC LEAK DETECTOR TEST

X-1000 INTRODUCTION

This technique describes the use of an ultrasonic leak detector to detect the ultrasonic energy produced by the flow of a gas from the lower pressure side of a very small opening in an envelope or barrier separating two regions at different pressures.

(a) Due to the low sensitivity [maximum sensitivity of 10^{-2} std cm^3/s (10^{-3} Pa m^3/s)] of this technique, it should not be utilized for the acceptance testing of vessels that will contain lethal or hazardous substances.

(b) This is a semiquantitative method used to detect and locate leaks and shall not be considered quantitative.

X-1020 GENERAL

X-1021 Written Procedure Requirements

X-1021.1 Requirements. The requirements of T-1021.1, Table X-1021, and the following as specified in this Article or referencing Code shall apply.

(a) leak standard
(b) test pressure
(c) soak time
(d) pressure gage
(e) acceptance criteria

X-1021.2 Procedure Qualification. The requirements of T-1021.3 and Table X-1021 shall apply.

X-1030 EQUIPMENT

X-1031 Instrument

An electronic ultrasonic leak detector capable of detecting acoustic energy in the range of 20 to 100 kHz shall be utilized. Leakage shall be indicated by one or more of the following signaling devices:

(a) Meter — A meter on the test instrument, or a probe, or both.

(b) Audio Device — A set of headphones that emit(s) audible indications.

X-1032 Capillary Calibration Leak Standard

A capillary type leak standard per Article 10, T-1063.2.

X-1060 CALIBRATION

X-1061 Standard Leak Size

The maximum leakage rate Q for the leak standard in X-1032 shall be 1×10^{-1} std cm^3/s (1×10^{-2} Pa m^3/s), unless otherwise specified by the referencing Code Section.

X-1062 Warm-up

The detector shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibration.

X-1063 Scanning Rate

The leak standard shall be attached to a pressure regulated gas supply and the pressure set to that to be used for the test. The detector shall be calibrated by directing the detector/probe towards the leak standard at the maximum scanning distance to be utilized during testing and noting the meter deflection and/or pitch of the audible signal as the detector/probe is scanned across the leak standard. The scanning rate shall not exceed that which can detect leakage rate Q from the leak standard.

X-1064 Frequency and Sensitivity

Unless otherwise specified by the referencing Code Section, the sensitivity of the detector shall be verified before and after testing, and at intervals of not more than 4 hr during testing. During any verification check, should the meter deflection or audible signal indicate that the detector/probe cannot detect leakage per X-1063, the instrument shall be recalibrated and areas tested after the last satisfactory calibration check shall be retested.

TABLE X-1021
REQUIREMENTS OF AN ULTRASONIC LEAK TESTING PROCEDURE

Requirement	Essential Variable	Nonessential Variable
Instrument manufacturer and model	X	
Surface preparation technique	X	
Metal temperature[1] (change to outside the range specified in this article or as previously qualified)	X	
Pressurizing gas	X	
Personnel performance qualification requirements, when required	X	
Scanning distance (maximum demonstrated during system calibration)		X
Scanning rate (maximum demonstrated during system calibration)		X
Signaling device		X
Scanning direction		X
Post testing cleaning technique		X
Personnel qualification requirements		X

NOTE:
(1) The minimum metal temperature during test shall not be below that specified in the referencing Code Section for the hydro, hydropneumatic, or pneumatic test. The minimum or maximum temperature during test shall also be compatible with the testing method.

X-1070 TEST

X-1071 Location of Test

The component to be tested shall, if possible, be removed or isolated from other equipment or structures that could generate ambient or system noise that can drown out leaks.

X-1072 Soak Time

Prior to testing, the test pressure shall be held a minimum of 15 min.

X-1073 Scanning Distance

After the required soak time per X-1072, the detector shall be passed over the test surface. The scanning distance shall not exceed that utilized to determine the maximum scanning rate in X-1063.

X-1074 Scanning Rate

The maximum scanning rate shall be as determined in X-1063.

X-1075 Leakage Detection

Leakage shall be indicated and detected according to X-1031.

X-1080 EVALUATION

X-1081 Leakage

Unless otherwise specified by the referencing Code Section, the area tested is acceptable when no leakage is detected that exceeds the allowable rate of 1×10^{-1} std cm^3/s (1×10^{-2} Pa m^3/s).

X-1082 Repair/Retest

When unacceptable leakage is detected, the location of the leak(s) shall be marked. The component shall then be depressurized, and the leak(s) repaired as required by the referencing Code Section. After repairs have been made, the repaired area or areas shall be retested in accordance with the requirements of this Appendix.

X-1090 DOCUMENTATION

X-1091 Examination Report

The report of examination shall contain the following information:

(a) procedure ID and revision;
(b) manufacturer and model number of instrument;
(c) calibration leak standard size and serial number;
(d) pressurizing gas and test pressure;
(e) soak time;
(f) maximum scanning distance and rate;
(g) map or record of rejectable leakage or areas cleared;
(h) identification of welds or areas scanned;
(i) examination personnel identity;
(j) date of examination.

X-1092 Performance Demonstration Report

Performance demonstrations, when required by the referencing Code Section, shall be documented.

ARTICLE 10
NONMANDATORY APPENDIX

APPENDIX A — SUPPLEMENTARY LEAK TESTING FORMULA SYMBOLS

A-10 APPLICABILITY OF THE FORMULAS

(a) The formulas in this Article provide for the calculated leak rate(s) for the technique used.

(b) The symbols defined below are used in the formulas of the appropriate Appendix.

(1) System sensitivity calculation:

S_1 = preliminary sensitivity (calculation of sensitivity), std $cm^3/s/div$ (Pa $m^3/s/div$)

S_2 = final sensitivity (calculation of sensitivity), std $cm^3/s/div$ (Pa $m^3/s/div$)

(2) System measured leakage rate calculation:

Q = measured leakage rate of the system (corrected for tracer gas concentration), std cm^3/s (Pa m^3/s)

(3) System Correction Factors:

$PSCF$ = Preliminary System Correction Factor

$FSCF$ = Final System Correction Factor

(4) Tracer gas concentration:

$\%TG$ = concentration of Tracer Gas, %

(5) Calibrated standard:

CL = calibrated leak leakage rate, std cm^3/s (Pa m^3/s)

(6) Instrument reading sequence:

M_1 = meter reading before test with calibrated leak open to the component [divisions, or std cm^3/s (Pa m^3/s)]

M_2 = meter reading before test with calibrated leak closed to component [divisions, or std cm^3/s (Pa m^3/s)] (system background noise reading)

M_3 = meter reading (registering component leakage) with calibrated leak closed [divisions, or std cm^3/s (Pa m^3/s)]

M_4 = meter reading (registering component leakage) with calibrated leak open [divisions, or std cm^3/s (Pa m^3/s)]

ARTICLE 11
ACOUSTIC EMISSION EXAMINATION OF FIBER-REINFORCED PLASTIC VESSELS

T-1110 SCOPE

(a) This Article describes or references requirements which are to be used in applying acoustic emission (AE) examination of new and inservice fiber reinforced plastic (FRP) vessels under pressure, vacuum, or other applied stress.

(b) Test pressure used during examination shall not exceed 1.5 times the maximum allowable working pressure (MAWP). Vacuum testing can be full design vacuum. These values are subordinate to stress values in specific procedures outlined in Section X, Part T, Rules Covering Testing, of the ASME Boiler and Pressure Vessel Code.

(c) This Article is limited to vessels with glass or other reinforcing material contents greater than 15% by weight.

T-1120 GENERAL

(a) When this Article is specified by a referencing Code Section, the method described in this Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are found in Mandatory Appendix III of this Article.

(b) Discontinuities located with AE shall be evaluated by other methods, e.g., visual, ultrasonic, liquid penetrant, etc., and shall be repaired and retested as appropriate.

T-1121 Vessel Conditioning

For tanks and pressure vessels that have been stressed previously, the operating pressure and/or load shall be reduced prior to testing according to the schedule shown in Table T-1121. In order to properly evaluate the AE examination, the maximum operating pressure or load on the vessel during the past year must be known, and recorded.

Table T-1121 is used as follows. The reduced pressure is divided by the maximum operating pressure and the quantity is expressed as a percent. This value is entered in the first column and the corresponding row in the second column shows the time required at the reduced pressure, prior to making an AE test. When the ratios fall between two values in the second column the higher value is used.

TABLE T-1121
REQUIREMENTS FOR REDUCED OPERATING LEVEL IMMEDIATELY PRIOR TO EXAMINATION

Percent of Operating Maximum Pressure and/or Load	Time Spent at Percent of Maximum Pressure and/or Load
10 or less	12 hr
20	18 hr
30	30 hr
40	2 days
50	4 days
60	7 days

EXAMPLE: For an inservice vessel, two factors must be known prior to making a test:
(1) The maximum operating pressure or load during the past year
(2) The test pressure

T-1122 Vessel Stressing

Arrangements shall be made to stress the vessel to the design pressure and/or load. The rate of application of stress and load shall be sufficient to expedite the examination with the minimum extraneous noise. Holding stress levels is a key aspect of an acoustic emission examination. Accordingly, provision must be made for holding the pressure and/or load at designated checkpoints.

(a) Atmospheric Vessels. Process liquid is the preferred fill medium for atmospheric vessels. If water must replace the process liquid, the designer and user shall be in agreement on the procedure to achieve acceptable stress levels.

(b) Vacuum Vessel Stressing. A controllable vacuum pump system is required for vacuum tanks.

T-1123 Vessel Support

All vessels shall be examined in their operating position and supported in a manner consistent with good engineering practice. Flat bottomed vessels examined in other than the intended location shall be mounted on a noise-isolating pad on a concrete base or equivalent during the examination.

T-1124 Environmental Conditions

The minimum acceptable vessel wall temperature is 40°F (5°C) during the examination. Evaluation criteria are based above 40°F (5°C). For vessels designed to operate above 120°F (50°C), the test fluid shall be within ±10°F (5°C) of the design operating temperature. [At the option of the owner, the vessel test pressure may be increased to compensate for testing at elevated temperatures (120°F) (50°C).] Sufficient time shall be allowed before the start of the test for the temperature of the vessel shell and the test fluid to reach equilibrium.

T-1125 Noise Elimination

Noise sources in the test frequency and amplitude range, such as rain, spargers, and foreign objects contacting the vessels, must be minimized since they mask the AE signals emanating from the structure. The filling inlet should be at the lowest nozzle or as near to the bottom of the vessel as possible, i.e., below the liquid level.

T-1126 Instrumentation Settings

Settings shall be determined as described in Appendix II of this Article.

T-1127 Sensors

(a) Sensor Mounting. The location and spacing of the sensor are in T-1141(c). The sensors shall be placed in the designated locations with the couplant specified in the testing procedure between the sensor and test article. Assure that adequate couplant is applied. The sensor shall be held in place utilizing methods of attachment which do not create extraneous signals, as specified in the test procedure. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated. The attachment method shall provide support for the signal cable (and preamplifier) to prevent the cable(s) from stressing the sensor or causing loss of coupling.

(b) Surface Contact. Sensors shall be mounted directly on the vessel surface, or integral waveguides shall be used. (Possible signal losses may be caused by coatings such as paint and encapsulants, as well as by construction surface curvature and surface roughness at the contact area.)

(c) High and Low Frequency Channels. An AE instrument channel is defined as a specific combination of sensor, preamplifier, filter, amplifier, and cable(s). Both high and low frequency channels shall be used. High frequency channels shall be used for detection and evaluation of AE sources. Low frequency channels shall be used to evaluate the coverage by high frequency sensors.

(d) High Frequency Sensors. (See Appendix I-1111.) Several high frequency channels shall be used for zone location of emission sources. This is due to greater attenuation at higher frequencies.

(e) Low Frequency Sensors. (See Appendix I-1112.) At least two low frequency channels shall be used. If significant activity is detected on the low frequency channels and not on high frequency channels, high frequency sensor location shall be evaluated by the examiner.

T-1128 Procedure Requirements

Acoustic emission examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) material and configurations to be examined including dimensions and product form;
(b) method for determination of sensor locations;
(c) sensor locations;
(d) couplant;
(e) method of sensor attachment;
(f) sensor type, frequency, and locations;
(g) acoustic emission instrument type and frequency;
(h) description of system calibration;
(i) data to be recorded and method of recording;
(j) report requirements;
(k) post-examination cleaning;
(l) qualification of the examiner(s).

T-1130 EQUIPMENT AND SUPPLIES

(a) The AE system consists of sensors, signal processing, display, and recording equipment. (See Appendix I.)

(b) The system shall be capable of recording AE counts and AE events above a threshold within a frequency range of 25 kHz–300 kHz and have sufficient channels to localize AE sources. It may incorporate (as an option) peak amplitude detection.

NOTE: Event detection is required for each channel.

Amplitude distributions are recommended for flaw characterization. The AE system is further described in Appendix I.

(c) Capability for measuring time and pressure shall be provided and recorded. The pressure and/or vacuum (in the vessel) shall be continuously monitored to an accuracy of ±2% of the maximum test pressure.

T-1140 APPLICATION REQUIREMENTS

T-1141 Vessels

(a) Equipment. (See T-1130 and Mandatory Appendix I.)

(b) System Calibration. (See Mandatory Appendix II.)

(1) Attenuation Characterization. Typical signal propagation losses shall be determined according to one of the following techniques. These techniques provide a relative measure of the attenuation. The peak amplitude from a pencil break may vary with surface hardness, resin condition, fiber orientation, and cure.

(2) For acoustic emission instrumentation with amplitude analysis:

Select a representative region of the vessel away from manways, nozzles, etc. Mount a high frequency AE sensor and locate points at distances of 6 in. (150 mm) and 12 in. (300 mm) from the center of the sensor along a line parallel to one of the principal directions of the surface fiber (if applicable). Select two additional points at 6 in. (150 mm) and 12 in. (300 mm) along a line inclined 45 deg. to the direction of the original points. At each of the four points, break 0.3 mm 2H pencil leads and record peak amplitude. A break shall be done at an angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. This amplitude data from successive lead breaks shall be part of the report.

(3) For systems without amplitude analysis:

Select a representative region of the vessel away from manways, nozzles, etc. Mount a high frequency AE sensor and break 0.3 mm pencil leads along a line parallel to one of the principal directions of the surface fibers.

Record the distances from the center of the sensor at which the recorded amplitude equals the reference amplitude and the threshold of acoustic emission detectability (see Appendix II). Repeat this procedure along a line inclined 45 deg. to the direction of the original line. This distance data shall be part of the report.

(c) Sensor Locations and Spacings. Locations on the vessel shell are determined by the need to detect structural flaws at critical sections, e.g., high stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. High frequency sensor spacings are governed by the attenuation of the FRP material. Sensor location guidelines for typical tank types are given in Nonmandatory Appendix A.

(1) Sensor Spacing. The recommended high frequency sensor spacing on the vessel shall be not greater than three times the distance at which the recorded amplitude from the attenuation characterization equals the threshold of detectability (see Appendix II). Low frequency sensors shall be placed in areas of low stress and at a maximum distance from one another.

(d) Systems Performance Check

(1) Sensor Coupling and Circuit Continuity Verification. Verification shall be performed following sensor mounting and system hookup and immediately following the test. A record of the verifications shall be recorded in the report.

(2) Peak Amplitude Response. The peak amplitude response of each sensor-preamplifier combination to a repeatable simulated acoustic emission source shall be taken and recorded following sensor mounting. The peak amplitude of the simulated event at a specific distance greater than 3 in. (75 mm) from each sensor shall not vary more than 6 dB from the average of all the sensors.

(3) Post-test verification using the procedure in (d)(2) above shall be done and recorded for the final report.

T-1142 Examination Procedure

(a) General Guidelines. The vessel is subjected to programmed increasing stress levels to a predetermined maximum while being monitored by sensors that detect acoustic emission caused by growing structural discontinuities.

Rates of filling and pressurization shall be controlled so as not to exceed the strain rate specified by the referencing Code Section.

The desired pressure will be attained with a liquid. Pressurization with a gas (air, N_2, etc.) is not permitted. A suitable manometer or other type gage shall be used to monitor pressure. Vacuum shall be attained with a suitable vacuum source.

A quick-release valve shall be provided to handle any potential catastrophic failure condition.

(b) Background Noise. Background noise should be identified, minimized, and recorded.

(1) Background Noise of Check Prior to Loading. AE monitoring of the vessel is required to identify and determine the level of spurious signals following the completion of the system performance check and prior to stressing the vessel. A recommended monitoring period is 10 min to 30 min. If background noise is excessive, the source of the noise shall be eliminated or the examination terminated.

(2) Background Noise During Examination. In the AE examiner's analysis of examination results, background noise shall be noted and its effects on test results evaluated. Sources of background noise include liquid splashing into a vessel; a fill rate that is too high; pumps, motors, agitators, and other mechanical devices; electromagnetic interference; and environment (rain, wind, etc.).

(c) Stressing

(1) Atmospheric Vessel Loading. Stressing sequences for new atmospheric vessels and vacuum vessels are shown in Figs. T-1142(c)(1)(a) and (b). The test algorithm-flowchart for this class of vessels is given in Fig. T-1142(c)(1)(c).

(2) Pressure Vessel Stressing. Pressure vessels which operate with superimposed pressures greater than 15 psi (100 kPa) above atmospheric shall be stressed as shown in Fig. T-1142(c)(2)(a). The test algorithm flowchart for this class of tanks is given in Fig. T-1142(c)(2)(b).

(3) For all vessels, the final stress hold shall be for 30 min. The vessel should be monitored continuously during this period.

(d) AE Activity. If significant [see T-1183(b)] AE activity is detected during the test on low frequency channels, and not on high frequency channels, the examiner may relocate the high frequency channels.

(e) Test Termination. Departure from a linear count/load relationship shall signal caution. If the AE count rate increases rapidly with load, the vessel shall be unloaded and the test terminated. [A rapidly (exponentially) increasing count rate indicates uncontrolled continuing damage and is indicative of impending failure.]

T-1160 CALIBRATION (See Mandatory Appendix II)

T-1180 EVALUATION

T-1181 Evaluation Criteria

The acoustic emission criteria shown in Table T-1181 are set forth as a basis for assessing the severity of structural flaws in FRP vessels. These criteria are based only on high frequency sensors. Low frequency sensors are used to monitor the entire vessel.

T-1182 Emissions During Load Hold E_H

The criterion based on emissions during load hold is particularly significant. Continuing emissions indicate continuing damage. Fill and other background noise will generally be at a minimum during a load hold.

T-1183 Felicity Ratio Determination

The felicity ratio is obtained directly from the ratio of the load at onset of emission and the maximum prior load. The felicity ratio is not measured during the first loading of pressure, atmospheric, or vacuum vessels.

(a) During the first loading of FRP vessels, the felicity ratio is measured from the unload/reload cycles. For subsequent loadings, the felicity ratio is obtained directly from the ratio of the load at onset of emission and the previous maximum load. A secondary felicity ratio is determined from the unload/reload cycles.

(b) The criterion based on felicity ratio is important for inservice vessels. The criterion provides a measure of the severity of previously induced damage. The onset of "significant" emission is used for determining measurement of the felicity ratio, as follows:

(1) more than 5 bursts of emission during a 10% increase in stress;

(2) more than $N_c/25$ counts during a 10% increase in stress, where N_c is the count criterion defined in Appendix II-1140;

(3) emission continues at a stress hold. For the purpose of this guideline, a short (1 min or less) nonprogrammed load hold can be inserted in the procedure.

T-1184 High Amplitude Events Criterion

The high amplitude events criterion is often associated with fiber breakage and is indicative of major structural damage in new vessels. For inservice and previously stressed vessels, emissions during a stress hold and felicity ratio are important.

T-1185 Total Counts Criterion

The criteria based on total counts are valuable for pressure or atmospheric and vacuum vessels. Pressure vessels, particularly during first stressing, tend to be noisy.

Excessive counts, as defined in Table T-1181, are important for all vessels, and are a warning of impending failure.

T-1190 DOCUMENTATION

T-1191 Report

The report shall include the following:

(a) complete identification of the vessel, including material type, source, method of fabrication, Manufacturer's name and code number, and previous history of maintenance, as well as relaxation operation data from Table T-1121, prior to testing;

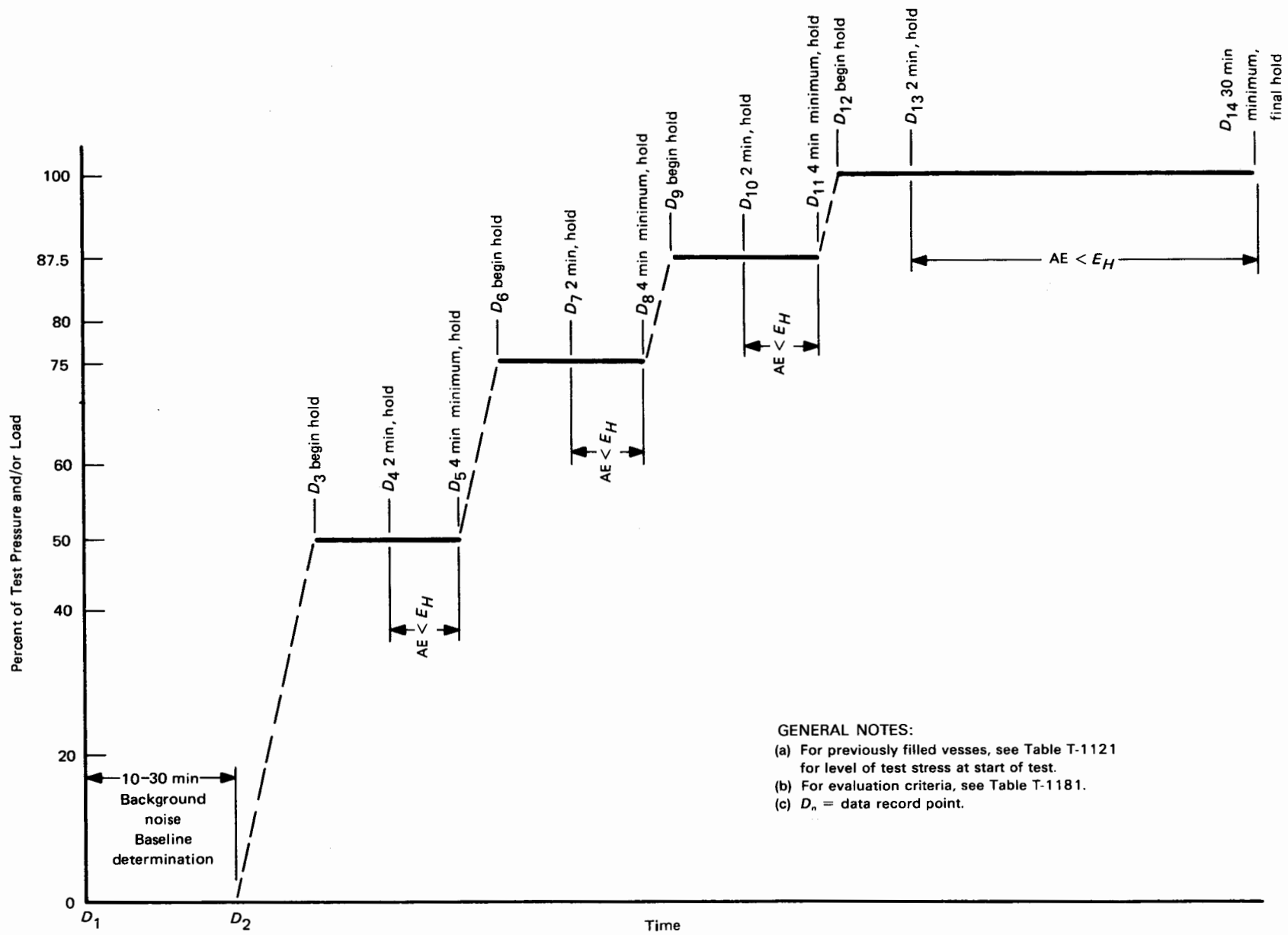


FIG. T-1142(c)(1)(a) ATMOSPHERIC VESSELS STRESSING SEQUENCE

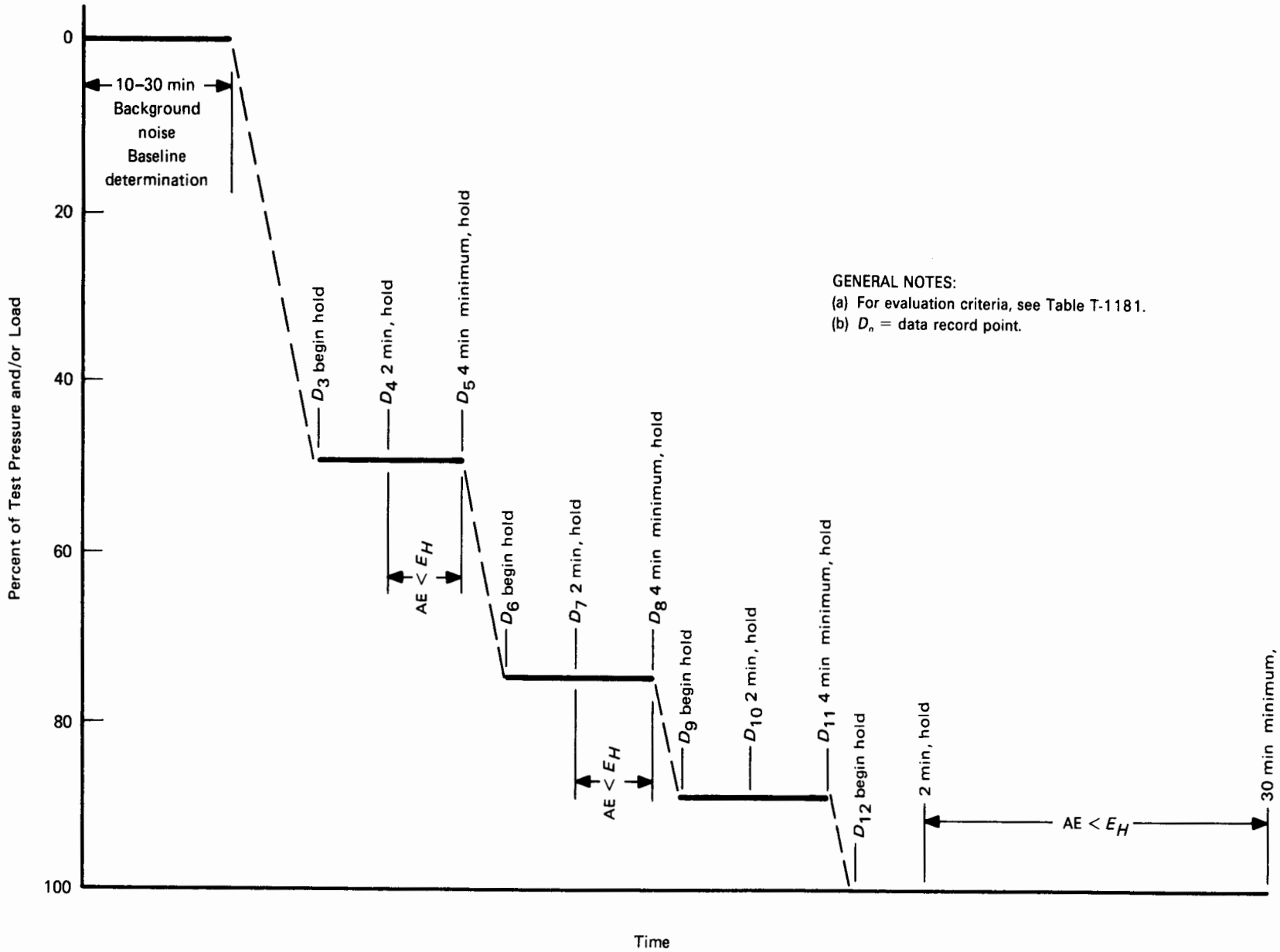


FIG. T-1142(c)(1)(b) VACUUM VESSELS STRESSING SEQUENCE

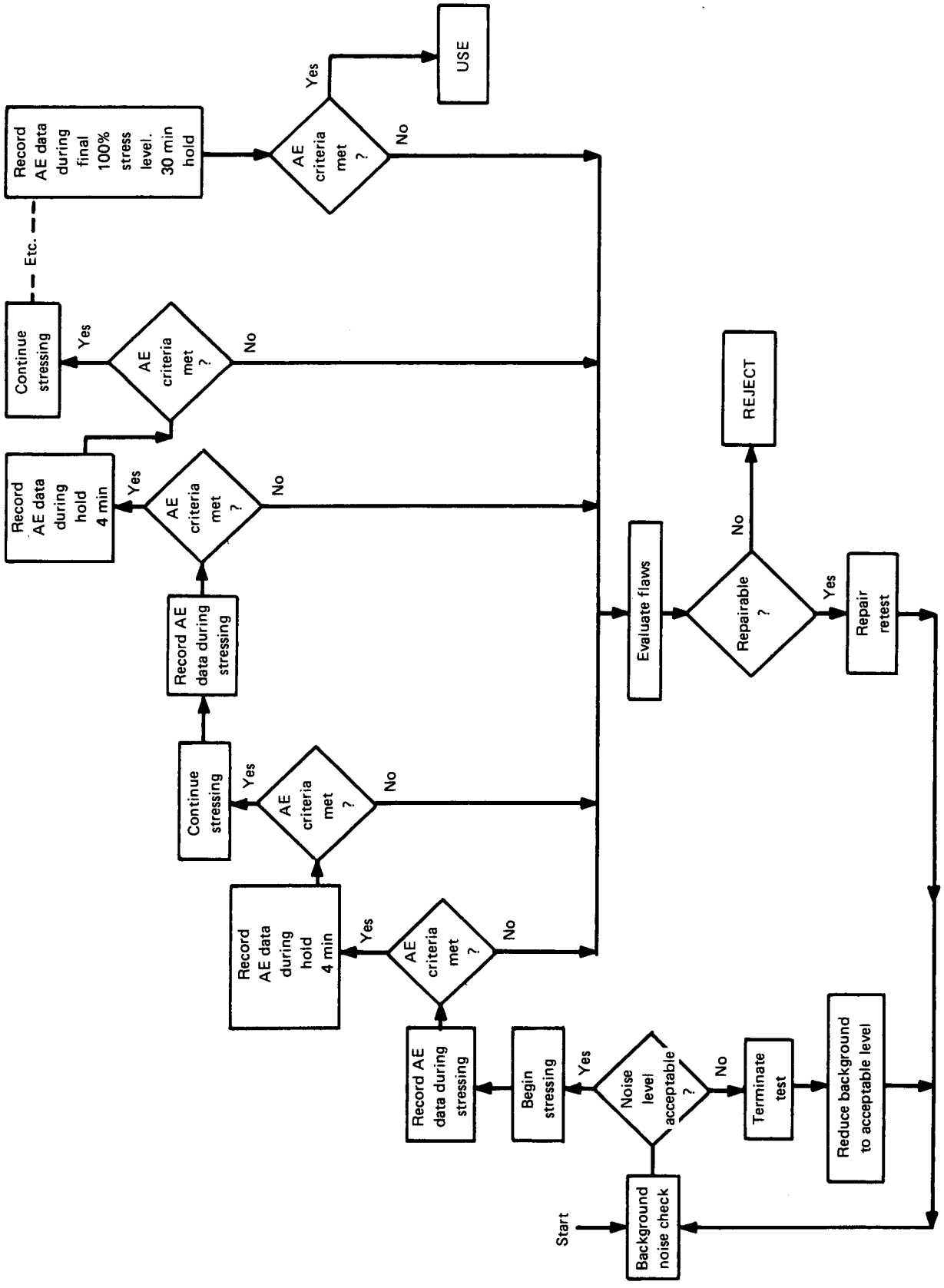


FIG. T-1142(c)(1)(c) TEST ALGORITHM — FLOWCHART FOR ATMOSPHERIC VESSELS

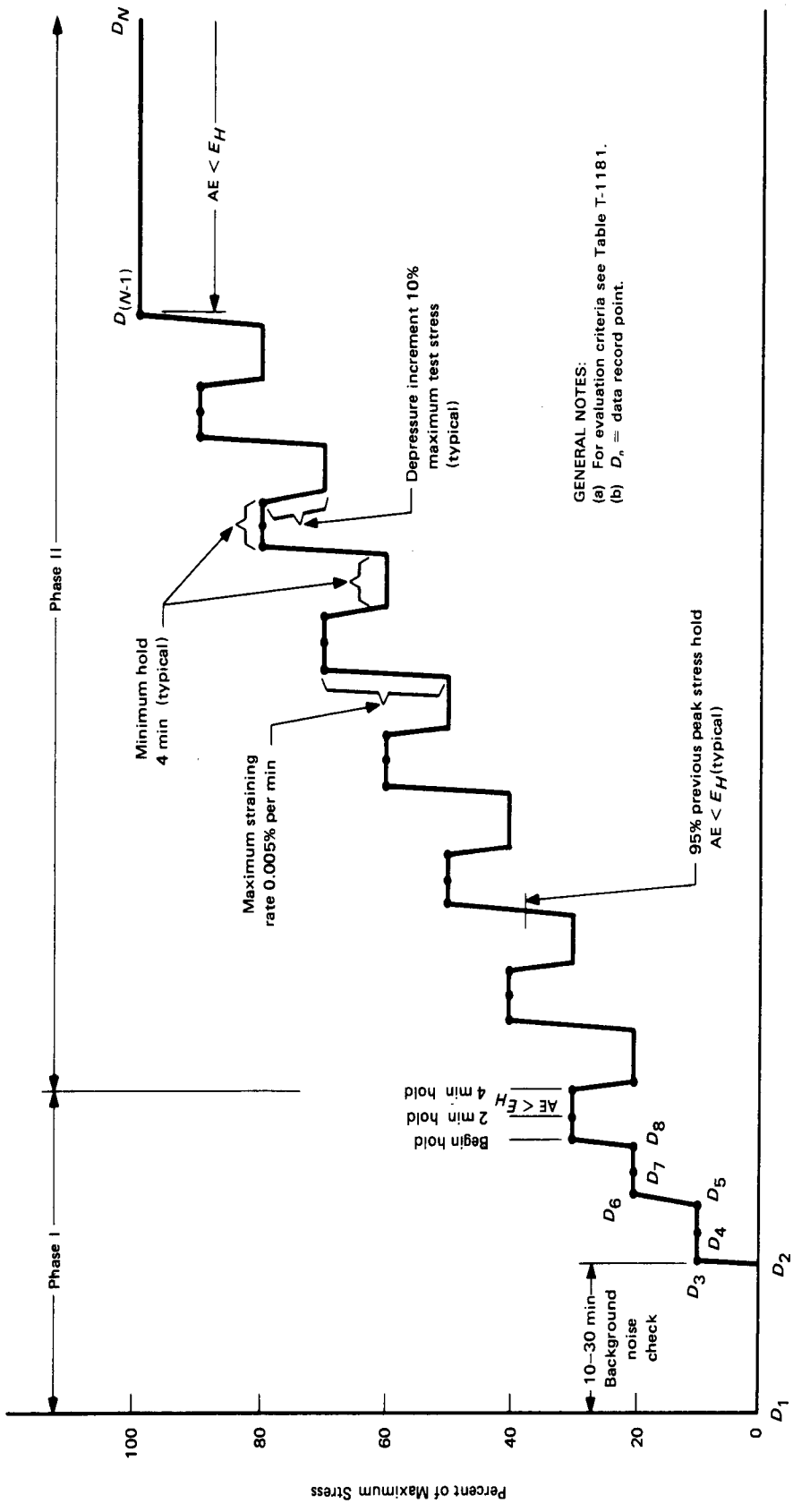


FIG. T-1142(c)(2)(a) PRESSURE VESSEL STRESSING SEQUENCE

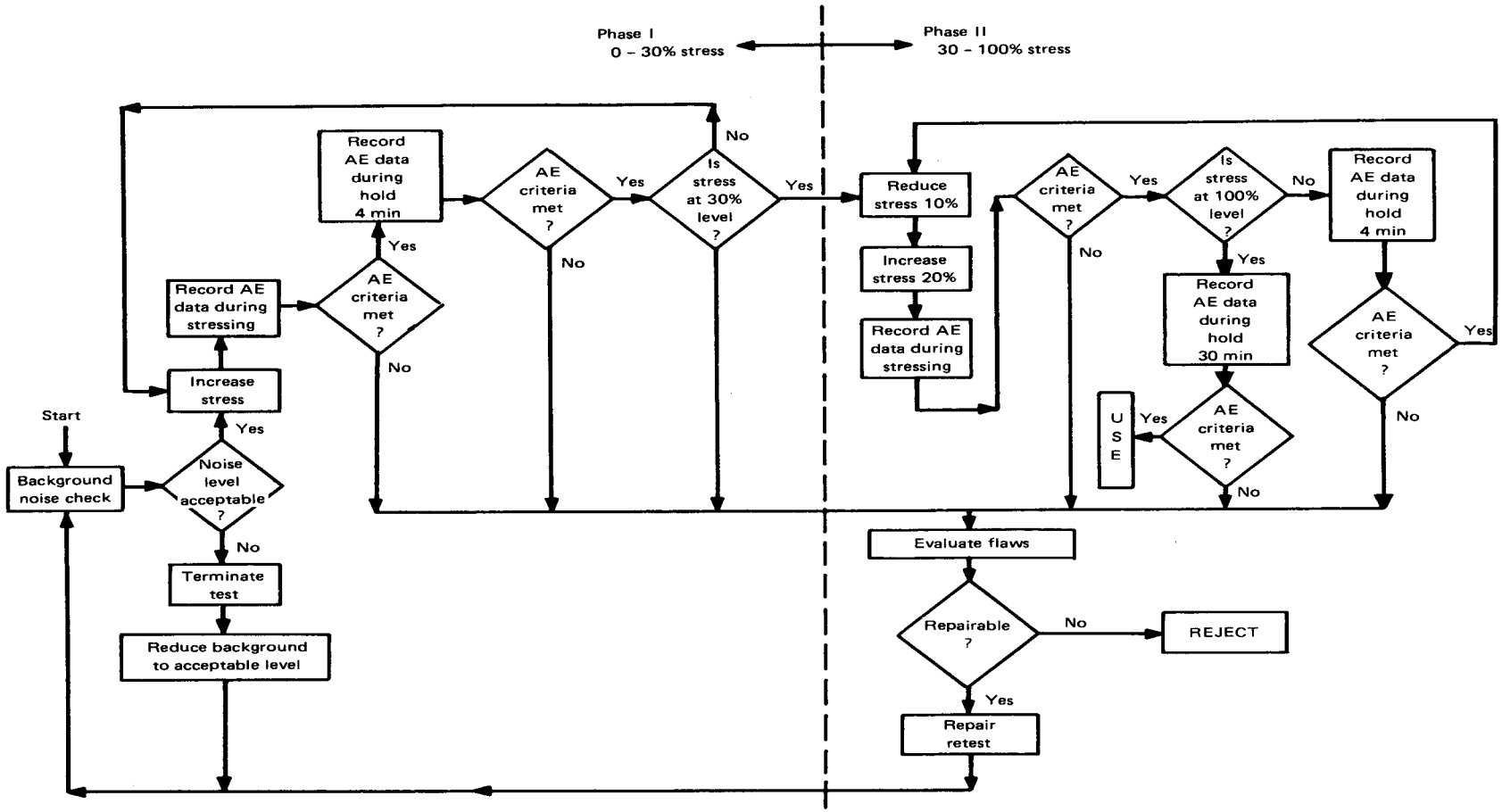


FIG. T-1142(c)(2)(b) ALGORITHM — FLOWCHART FOR PRESSURE VESSELS

TABLE T-1181
EVALUATION CRITERIA
Atmospheric (Liquid Head) and Additional[1] Superimposed Pressure

	First Loading	Subsequent Loading	
Emissions during hold	Less than E_H events beyond time T_H, none having an amplitude greater than A_M [Note (2)]	Less than E_H events beyond time T_H	Measure of continuing permanent damage [Note (3)]
Felicity ratio	Greater than felicity ratio F_A	Greater than felicity ratio F_A	Measure of severity of previous induced damage
Total [Note (4)]	Not excessive [Note (5)]	Less than N_c total counts	Measure of overall damage during a load cycle
M [Note (6)]	No events with a duration greater than M	No events with a duration greater than M	Measure of delamination, adhesive bond failure, and major crack growth
Number of events greater than reference amplitude threshold	Less than E_A events	Less than E_A events	Measure of high energy microstructure failures. This criterion is often associated with fiber breakage.

GENERAL NOTE: A_M, E_A, E_H, F_A, N_c, and M are acceptance criteria values specified by the referencing Code Section; T_H is specified hold time.

NOTES:
(1) Above atmospheric
(2) See Appendix II-1140 for definition of A_M.
(3) Permanent damage can include microcracking, debonding, and fiber pull out.
(4) Varies with instrumentation manufacturer; see Appendix II for functional definition of N_c. Note that counts criterion N_c may be different for first and subsequent fillings.
(5) Excessive counts are defined as a significant increase in the rate of emissions as a function of load. On a plot of counts against load, excessive counts will show as a departure from linearity.
(6) If used, varies with instrumentation manufacturer; see Appendix II-1150 for functional definition.

(b) vessel sketch or Manufacturer's drawing with dimensions and sensor locations;

(c) test liquid employed;

(d) test liquid temperature;

(e) test sequence — load rate, hold times, and hold levels;

(f) correlation of test data with the acceptance criteria;

(g) a sketch or Manufacturer's drawings showing the location of any zone not meeting the evaluation criteria;

(h) any unusual effects or observations during or prior to the test;

(i) date(s) of test;

(j) name(s) and qualifications of the test operator(s);

(k) complete description of AE instrumentation including Manufacturer's name, model number, sensor type, system gain, etc.

T-1192 Record

(a) A permanent record of AE data includes:

(1) AE events above threshold vs time for zones of interest;

(2) total counts vs time, etc.;

(3) signal propagation loss.

(b) The AE data shall be maintained with the records of the vessel.

ARTICLE 11
MANDATORY APPENDICES

APPENDIX I — INSTRUMENTATION PERFORMANCE REQUIREMENTS

I-1110 AE SENSORS

AE sensors shall be temperature stable over the range of use which may be 40°F–200°F (5°C–95°C), and shall not exhibit sensitivity changes greater than 3 dB over this range. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice and/or differential (anticoincident) element design. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response.

I-1111 High Frequency Sensors

These sensors shall have a resonant response at 100 kHz–200 kHz. Minimum sensitivity shall be −80 dB referred to 1 volt/microbar, determined by face-to-face ultrasonic calibration. AE sensors used in the same test should not vary in peak sensitivity more than 3 dB from the average.

I-1112 Low Frequency Sensors

These sensors shall have a resonant response between 25 kHz and 75 kHz. Minimum sensitivity shall be comparable to, or greater than, commercially available high sensitivity accelerometers with resonant response in that frequency range. In service, these sensors may be wrapped or covered with a sound-absorbing medium to limit interference by airborne noise, if permitted in the procedure used in making the examination.

I-1120 SIGNAL CABLE

The signal cable from sensor to preamp shall not exceed 6 ft (1.8 m) in length and shall be shielded against electromagnetic interference. This requirement is omitted where the preamplifier is mounted in the sensor housing, or a line-driving (matched impedance) sensor is used.

I-1130 COUPLANT

Commercially available couplants for ultrasonic flaw detection accumulated above second threshold may be used (high setting adhesives may also be used, provided couplant sensitivity is not significantly lower than with fluid couplants). Couplant selection should be made to minimize changes in coupling sensitivity during a test. Consideration should be given to testing time and the surface temperature of the vessel. The couplant and method of attachment are specified in the written procedure.

I-1140 PREAMPLIFIER

The preamplifier, when used, shall be mounted in the vicinity of the sensor, or may be in the sensor housing. If the preamp is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. Unfiltered frequency response shall not vary more than 3 dB over the frequency range of 25 kHz–300 kHz, and over the temperature range of 40°F–125°F (5°C–50°C). For sensors with integral preamps, frequency response characteristics shall be confined to a range consistent with the operational frequency of the sensor.

I-1150 FILTERS

Filters shall be of the band pass or high pass type, and shall provide a minimum of −24 dB/octave signal attenuation. Filters may be located in preamplifier or post-preamplifier circuits, or may be integrated into the component design of the sensor, preamp, or processor to limit frequency response. Filters and/or integral design characteristics shall insure that the principal processing frequency for high frequency sensors is not less than 100 kHz, and for low frequency sensors not less than 25 kHz.

I-1160 POWER-SIGNAL CABLE

The cable providing power to the preamplifier and conducting the amplified signal to the main processor

shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per 100 ft (30 m) of cable length. The recommended maximum cable length is 500 ft (150 m) to avoid excessive signal attenuation. Digital or radio transmission of signals is allowed if consistent with standard practice in transmitting those signal forms.

I-1161 Power Supply

A stable grounded electrical power supply, meeting the specifications of the instrumentation, shall be used.

I-1170 MAIN AMPLIFIER

The main amplifier, if used, shall have signal response with variations not exceeding 3 dB over the frequency range of 25 kHz–300 kHz, and temperature range of 40°F–125°F (5°C–50°C). The written procedure shall specify the use and nomenclature of the main amplifier.

The main amplifier shall have adjustable gain, or an adjustable threshold for event detection and counting.

I-1180 MAIN PROCESSOR

I-1181 General

The main processor(s) shall have a minimum of two active data processing circuits through which high frequency and low frequency sensor data will be processed independently. If independent channels are used, the processor shall be capable of processing events and counts on each channel. No more than two sensors may be commoned into a single preamplifier.

If a summer or mixer is used, it shall provide a minimum processing capability for event detection on eight channels (preamp inputs).

Low frequency sensor information will be processed for emission activity. Total counts will be processed from the high frequency sensors only. Events accumulated above second threshold (high amplitude events) will be processed from the high frequency sensors only. The high amplitude signal threshold may be established through signal gain reduction, threshold increase, or peak amplitude detection.

(a) Threshold. The AE instrument used for examination shall have a threshold control accurate to within ±2 dB over its useful range.

(b) Counts. The AE instrument used for examination shall detect counts over a set threshold within an accuracy of ±5%.

(c) Events. The AE instrument used for examination shall be capable of continuously measuring 100 events ±1 event/sec, over a set threshold.

(d) Peak Amplitude. When peak amplitude detection is used, the AE instrument used for examination shall measure the peak amplitude within an accuracy of ±2 dB over a set threshold.

(e) M. The AE instrument used for examination shall be capable of measuring an *M* value (if used).

(f) Field Performance Verification. At the beginning of each vessel test the performance of each channel of the AE instrument shall be checked using an electronic waveform generator and a stress wave generator.

(g) Waveform Generator. This device shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. As a minimum, it shall be able to verify system operation for threshold, counts, and if used, duration, and peak amplitude measurements over the range of 25 kHz–200 kHz.

(h) Stress Wave Generator. This device shall transmit a stress wave pulse into the sensor. AE instrumentation response shall be within 5 dB of the response of the same sensor model when new.

The AE channel response to a single lead break shall be within 5 dB of the channel response of the same sensor model when new.

I-1182 Peak Amplitude Detection

If peak amplitude detection is practiced, comparative calibration must be established per the requirements of Appendix II. Usable dynamic range shall be a minimum of 60 dB with 5 dB resolution over the frequency band of 100 kHz–300 kHz, and the temperature range of 40°F–125°F (5°C–50°C). Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values may be stated in volts or dB, but must be referenced to a fixed gain output of the system (sensor or preamp).

I-1183 Signal Outputs and Recording

The processor as a minimum shall provide outputs for permanent recording of total counts for high frequency sensors, events by channel (zone location), and total events above the reference amplitude threshold for high frequency sensors. A sample schematic is shown in Fig. I-1183.

APPENDIX II — INSTRUMENT CALIBRATION

II-1110 GENERAL

The performance and threshold definitions vary for different types of acoustic emission equipment. Parameters such as counts, amplitude, energy, and *M* vary from

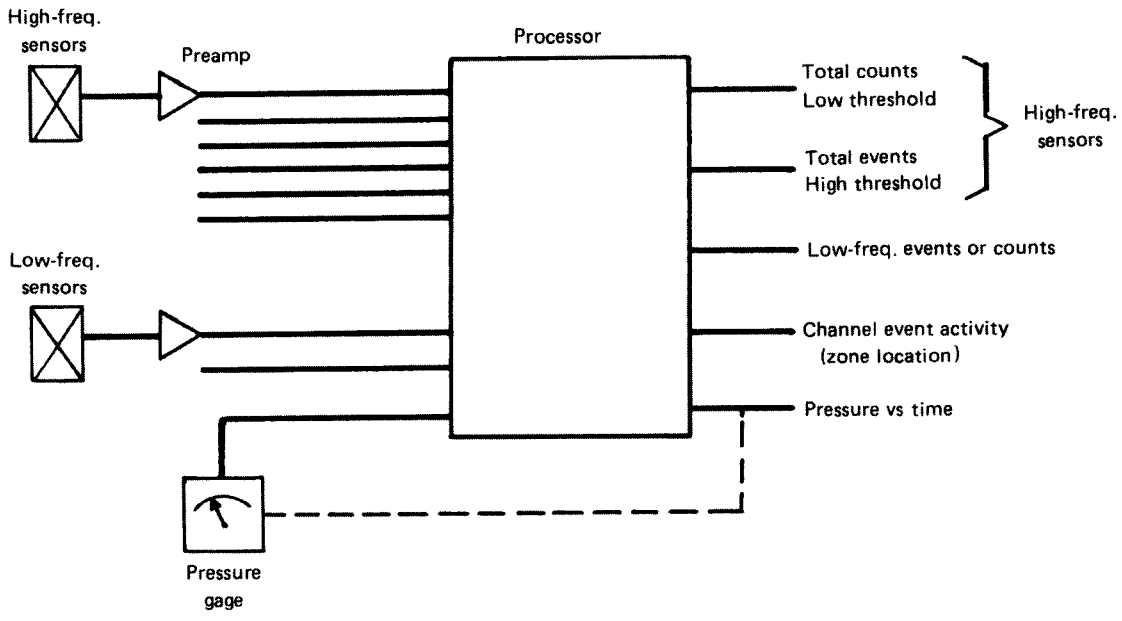


FIG. I-1183 SAMPLE OF SCHEMATIC OF AE INSTRUMENTATION FOR VESSEL EXAMINATION

manufacturer to manufacturer, and from model to model by the same manufacturer. This Appendix defines procedures for determining the threshold of acoustic emission detectability, reference amplitude threshold, and count criterion N_c.

The procedures defined in this Appendix are intended for baseline instrument calibration at 60°F to 80°F (15°C to 25°C). Instrumentation users shall develop calibration techniques traceable to the baseline calibration outlined in this Appendix. For field use, electronic calibrators, small portable samples (acrylic or similar), can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

II-1120 THRESHOLD

Threshold of acoustic emission detectability shall be determined using a 4 ft × 6 ft × ½ in. (1.2 m × 1.8 m × 13 mm) 99% pure lead sheet. The sheet shall be suspended clear of the floor. The threshold of detectability is defined as the average measured amplitude of ten events generated by 0.3 mm pencil (2H) lead break at a distance of 4 ft 3 in. (1.3 m) from the sensor. A break shall be done at an angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 6 in. (150 mm) from the 4 ft (1.2 m) side and mid-distance between the 6 ft (1.8 m) sides.

II-1130 REFERENCE AMPLITUDE THRESHOLD

For large amplitude events, the reference amplitude threshold shall be determined using a 10 ft × 2 in. × ¾ in. (3.0 m × 50 mm × 19 mm) clean, mild steel bar. The bar shall be supported at each end by elastomeric, or similar, isolating pads. The reference amplitude threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 7 ft (2.1 m) from the sensor (see Appendix II-1120). A break shall be done at an angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 12 in. (300 mm) from the end of the bar on the 2 in. (50 mm) wide surface.

II-1140 COUNT CRITERION N_c AND A_M VALUE

The count criterion N_c shall be determined either before or after the test using a 0.3 mm pencil (2H) lead broken on the surface of the vessel. A break shall be done at an angle of approximately 30 deg. to the test surface with a 0.1 in. (2.5 mm) lead extension. Calibration points shall be chosen so as to be representative of different constructions and thicknesses and should be performed above and below the liquid line (if applicable), and away from manways, nozzles, etc.

Two calibrations shall be carried out for each calibration point. One calibration shall be in the principal direction of the surface fibers (if applicable), and the second calibration shall be carried out along a line at 45 deg. to the direction of the first calibration. Breaks shall be at a distance from the calibration point so as to provide an amplitude decibel value A_M midway between the threshold of detectability (see Appendix II-1120) and reference amplitude threshold (see Appendix II-1130).

The count criterion N_c shall be based on the counts recorded from a defined (referencing Code Section) number of 0.3 mm pencil (2H) lead breaks at each of the two calibration points.

When applying the count criterion, the count criterion value, which is representative of the region where activity is observed, should be used.

II-1150 MEASUREMENT OF *M*

M is a measure of delamination, adhesive bond failure, or major crack growth. Different techniques are used by different instrument manufacturers for measuring *M*. The units of the *M* value will vary depending upon the techniques and instrument that are used. Numerical values of *M* are normally defined from an electronically generated input signal. The value of *M* will be specified by the referencing Code Section.

II-1160 FIELD PERFORMANCE

As installed on the vessel, no channel shall deviate by more than 6 dB from the average peak response of all channels when lead breaks, or other simulated transient sources, are introduced 6 in. (150 mm) from the sensor.

APPENDIX III — GLOSSARY OF TERMS FOR ACOUSTIC EMISSION EXAMINATION OF FIBER-REINFORCED PLASTIC VESSELS

III-1110 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms related to examination of fiber-reinforced plastic vessels with acoustic emission.

III-1120 GENERAL REQUIREMENTS

(a) The standard terminology for Nondestructive Examinations, ASTM E 1316, has been adopted by the Committee as SE-1316.

(b) SE-1316 defines the terms that are used in conjunction with this Article.

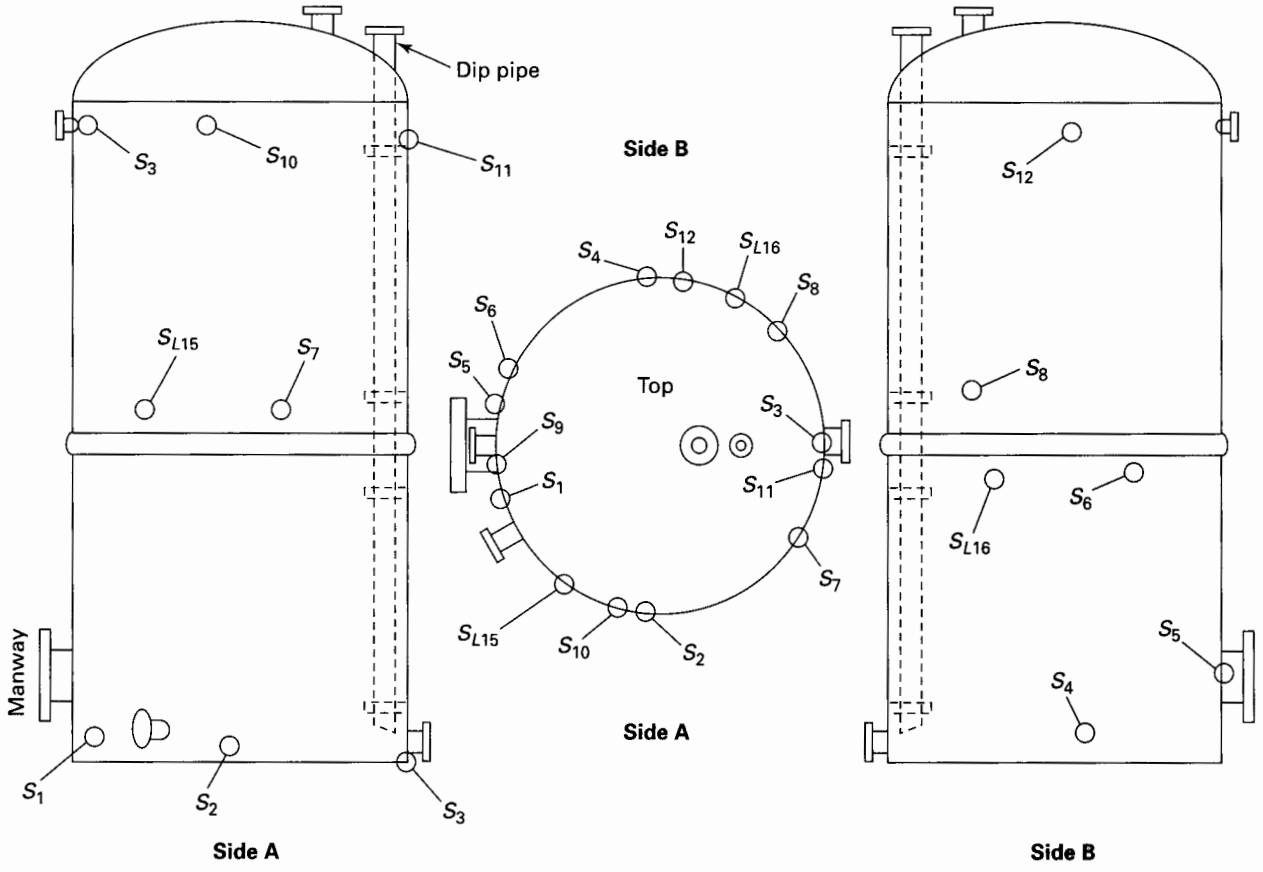
(c) For general terms, such as *interpretation, flaw, discontinuity, evaluation*, etc., refer to Article 1, Mandatory Appendix I.

ARTICLE 11
NONMANDATORY APPENDIX

Appendix A begins on the next page.

APPENDIX A
SENSOR PLACEMENT GUIDELINES

CASE 1 – ATMOSPHERIC VERTICAL VESSEL



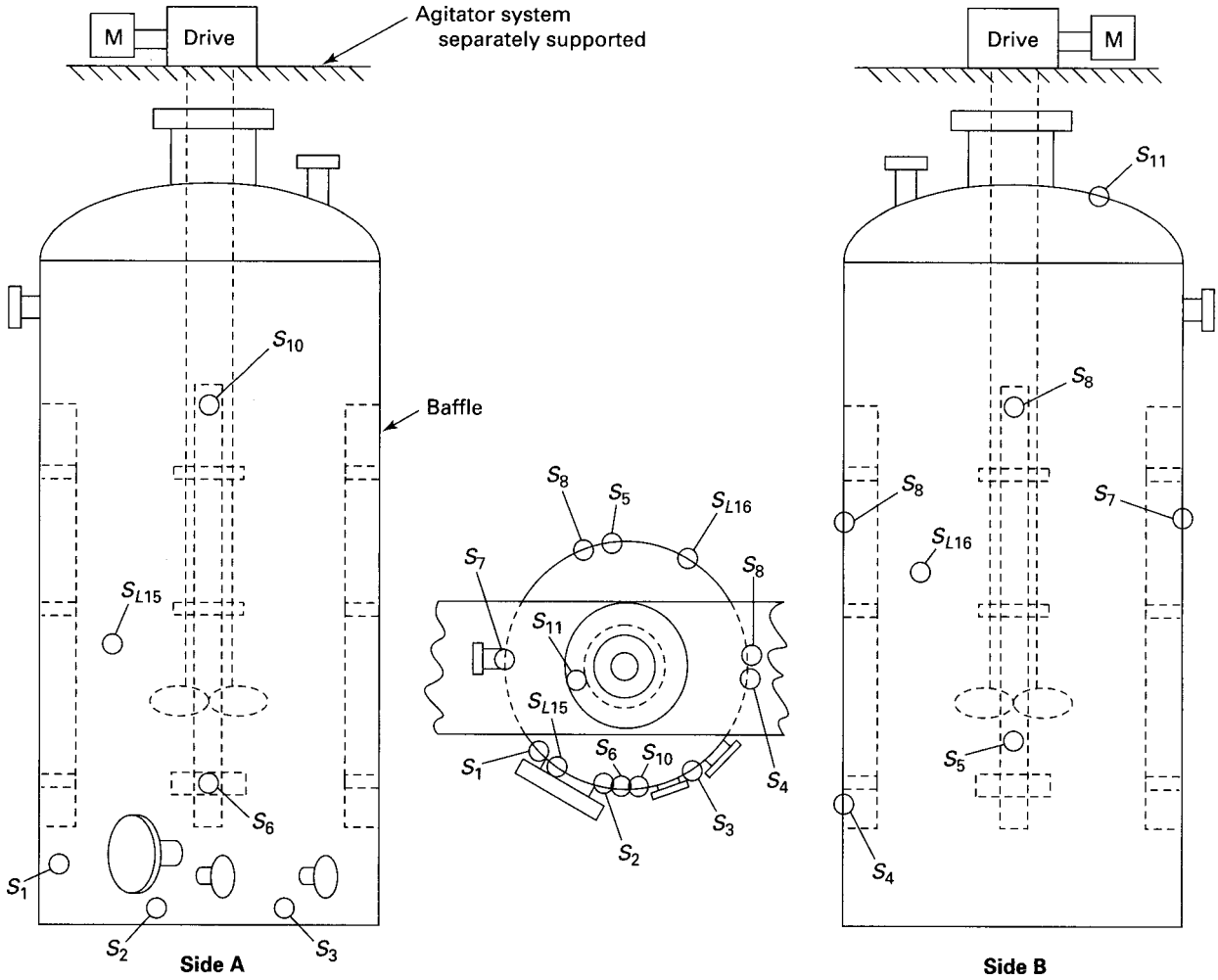
GUIDELINES:

(1) The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (150 mm to 300 mm) away from knuckle on shell.

(2) The secondary bond joint areas are suspect, e.g., nozzles, manways, shell butt joint, etc. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (75 mm to 150 mm) from intersection with shell and below. The shell butt joint region is important. Locate the two high frequency sensors up to 180 deg. apart—one above and one below the joint.

(3) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height—one above and one below the joint. Space as far apart as possible—up to 180 deg. and at 90 deg. to the high frequency pair.

CASE 2 – ATMOSPHERIC VERTICAL VESSEL



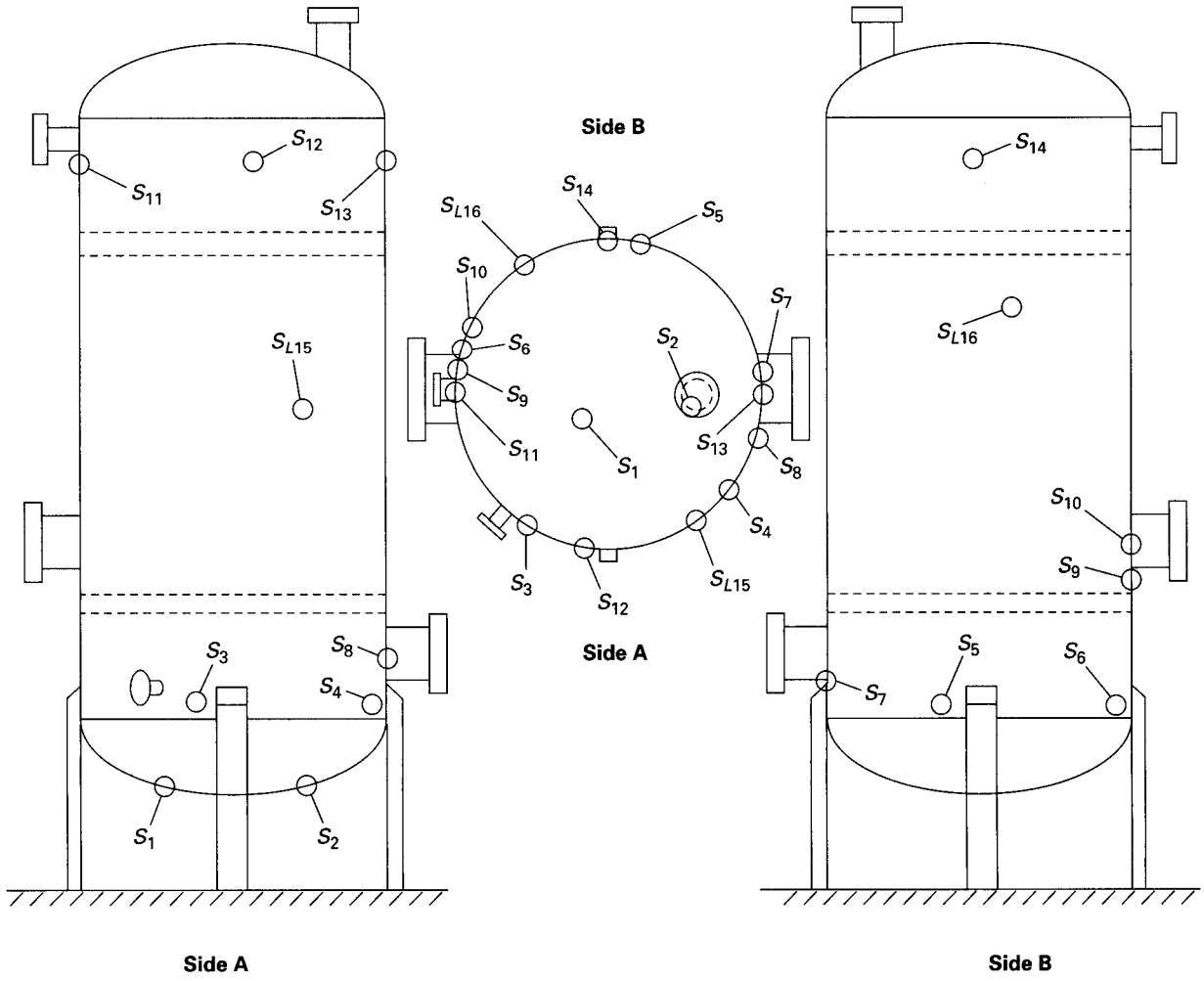
GUIDELINES:

(1) The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (150 mm to 300 mm) away from the knuckle on shell. In this example, sensors are so placed that the bottom nozzles, manways, and baffle areas plus the knuckle regions are covered.

(2) The secondary bond joint areas are suspect, e.g., nozzles, manways, and baffle attachments to shell. See the last sentence of above for bottom region coverage in this example. Note sensor adjacent to agitator shaft top manway. This region should be checked with agitator on.

(3) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height, one above and one below joint. They should be spaced as far apart as possible—up to 180 deg.

CASE 3 – ATMOSPHERIC / PRESSURE VESSEL



GUIDELINES:

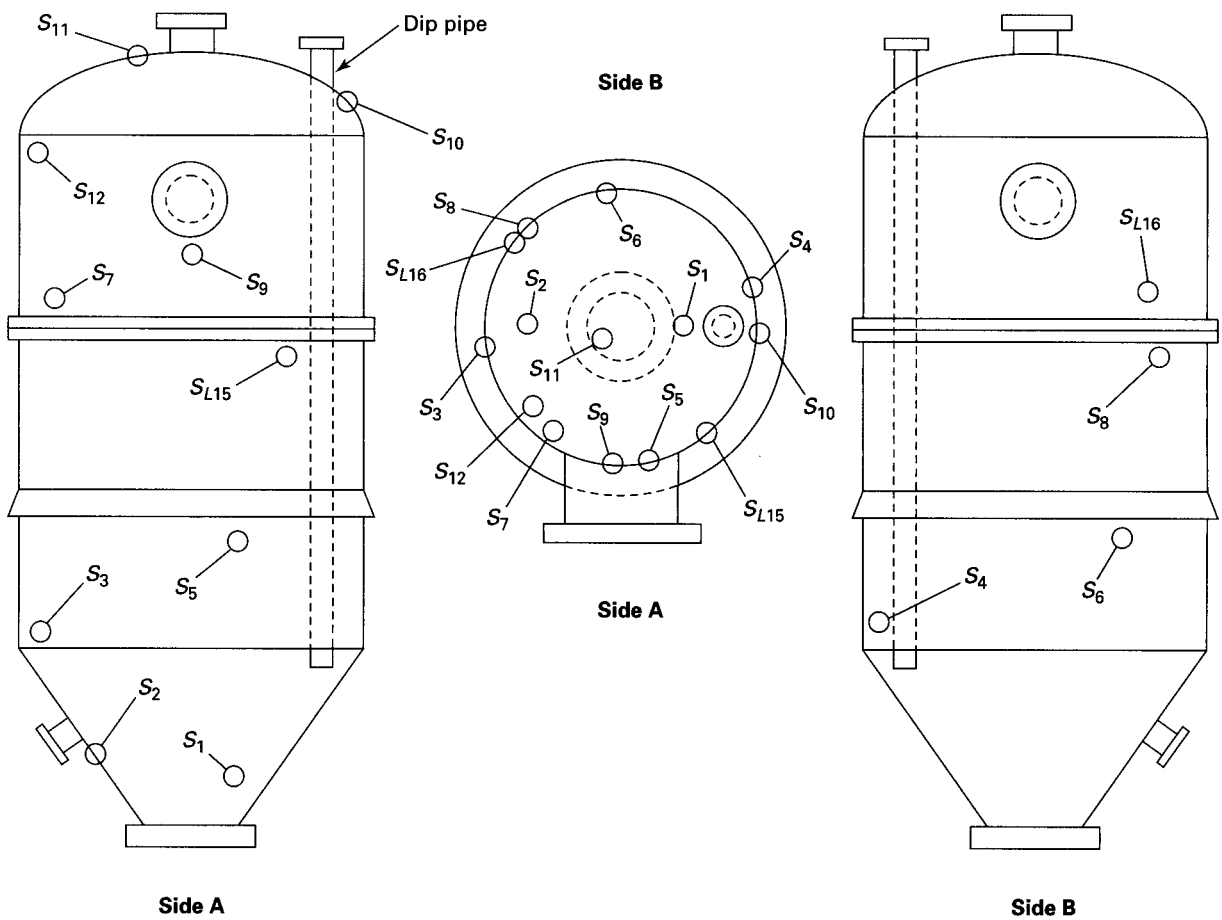
(1) The bottom head is highly stressed. Locate two sensors approximately as shown.

(2) The bottom knuckle region is critical. Locate sensors to provide adequate coverage, e.g., approximately every 90 deg. and 6 in. to 12 in. (150 mm to 300 mm) away from knuckle on shell. The top knuckle region is similarly treated.

(3) The secondary bond areas are suspect, i.e., nozzles, manways, and leg attachments. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (75 mm to 150 mm) from the intersection with shell and below. For leg attachments, there should be a sensor within 12 in. (300 mm) of the shell-leg interface.

(4) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height—one above and one below joint. They should be spaced as far apart as possible up to 180 deg.

CASE 4 – ATMOSPHERIC / PRESSURE VERTICAL VESSEL

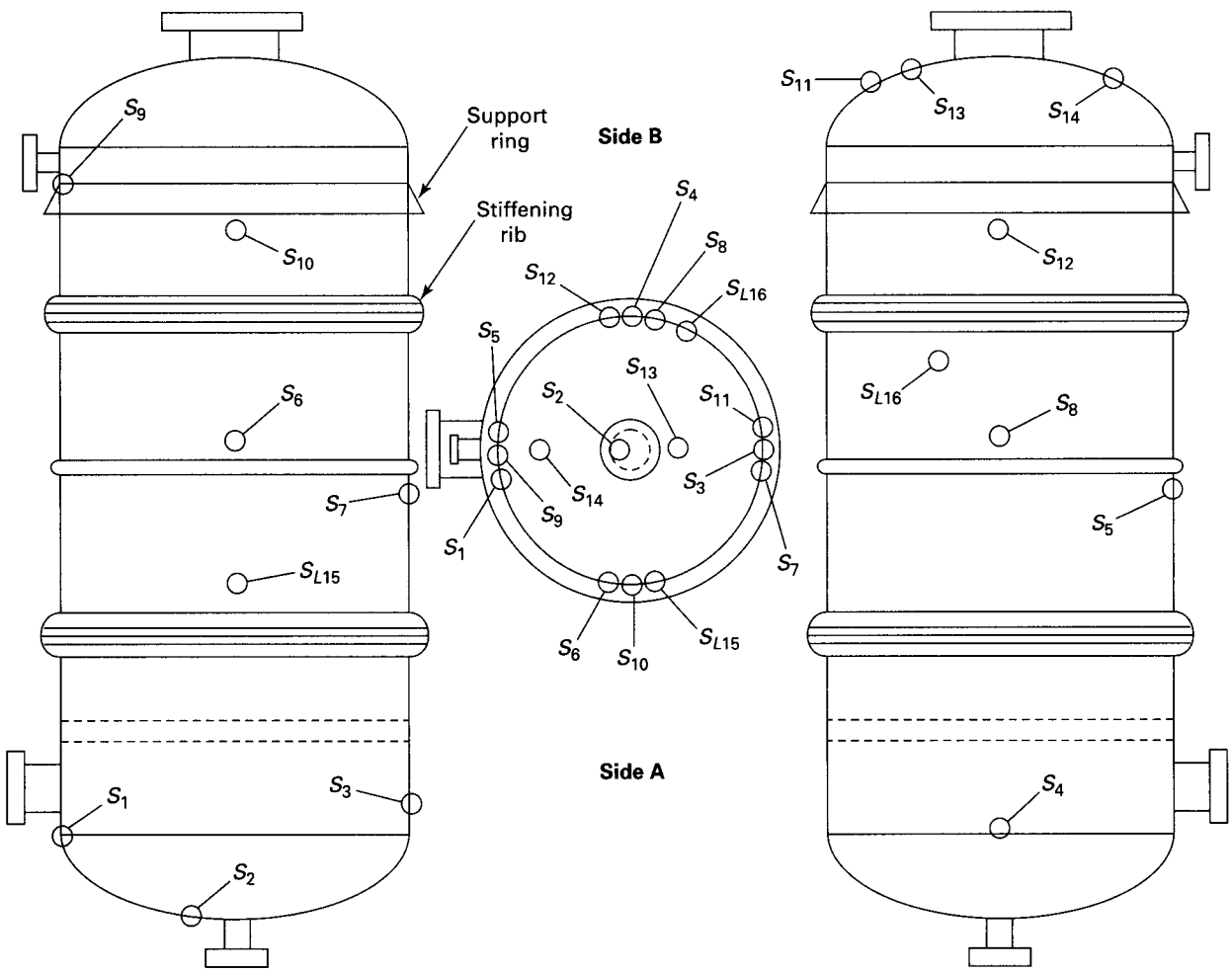


GUIDELINES:

(1) The secondary bond joint areas are suspect, i.e., nozzles, manways, and body flanges. Particularly critical in this vessel are the bottom manway and nozzle. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (75 mm to 150 mm) from intersection with shell and below. The bottom flange in this example is covered by sensor 3 in. to 6 in. (75 mm to 150 mm) above the manway. The body flange is covered by low frequency sensors S_{L15} and S_{L16}—one above and one below the body flange and spaced as far apart as possible—up to 180 deg. Displaced approximately 90 deg. from this pair and spaced up to 180 deg. apart are the two high frequency sensors—one above and one below the flange.

(2) The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, i.e., approximately every 90 deg. and 3 in. to 6 in. (75 mm to 150 mm) away from knuckle on shell.

CASE 5 – ATMOSPHERIC / VACUUM VERTICAL VESSEL



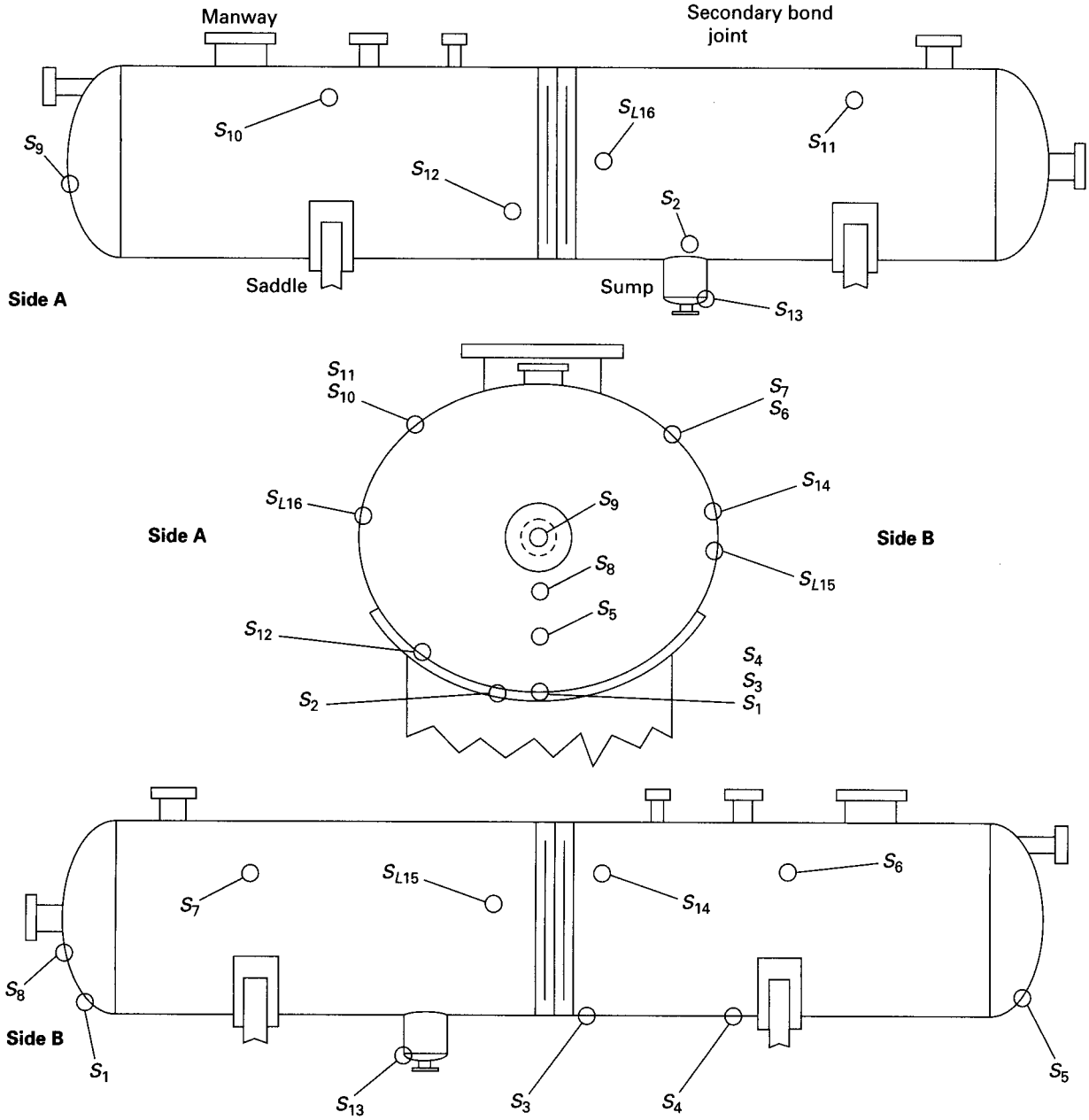
GUIDELINES:

(1) The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, i.e., approximately every 90 deg. and 6 in. to 12 in. (150 mm to 300 mm) away from knuckle on shell.

(2) The secondary bond joint areas are critical, e.g., nozzles, manways, and shell butt joints. For nozzles and manways, the preferred sensor location is 3 in. to 6 in. (75 mm to 150 mm) from the intersection with the shell (or head) and below, where possible. The shell butt joint region is important. Locate sensors up to 180 deg. apart where possible and alternately above and below joint.

(2) The low frequency sensors shown as S_{L15} and S_{L16} should be located at vessel mid-height—one above and one below the joint. They should be spaced as far apart as possible—up to 180 deg. and at 90 deg. to other pair.

CASE 6 – ATMOSPHERIC / PRESSURE HORIZONTAL TANK

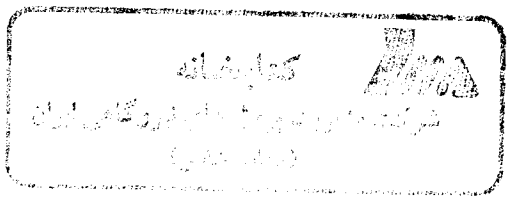


GUIDELINES:

(1) The discontinuity stresses at the intersection of the heads and the shell in the bottom region are important. Sensors should be located to detect structural problems in these areas.

(2) The secondary bond joint areas are suspect, e.g., shell butt joint, nozzles, manways, and sump. The preferred sensor location is 3 in. to 6 in. (75 mm to 150 mm) from intersecting surfaces of revolution. The shell butt joint region is important. Locate the two high frequency sensors up to 180 deg. apart—one on either side of the joint.

(3) The low frequency sensors shown as S_{L15} and S_{L16} should be located in the middle of the tank—one on either side of the joint. They should be spaced as far apart as possible, i.e., up to 180 deg. and at 90 deg. to high frequency pair.



ARTICLE 12
ACOUSTIC EMISSION EXAMINATION OF METALLIC VESSELS DURING PRESSURE TESTING

T-1210 SCOPE

This Article describes methods for conducting acoustic emission (AE) examination of metallic pressure vessels during acceptance pressure testing when specified by a referencing Code Section. When AE examination in accordance with this Article is specified, the referencing Code Section shall be consulted for the following specific requirements:

(a) personnel qualification/certification requirements;

(b) requirements/extent of examination and/or volume(s) to be examined;

(c) acceptance/evaluation criteria;

(d) standard report requirements;

(e) content of records and record retention.

When this Article is specified by a referencing Code Section, the AE method described in the Article shall be used together with Article 1, General Requirements. Definitions of terms used in this Article may be found in Mandatory Appendix III of this Article.

T-1220 GENERAL

T-1220.1 The principal objectives of AE examination are to locate and monitor emission sources caused by surface and internal discontinuities in the vessel wall, welds, and fabricated parts and components.

T-1220.2 All relevant indications caused by AE sources shall be evaluated by other methods of nondestructive examination.

T-1221 Vessel Stressing

Arrangements shall be made to stress the vessel using internal pressure as specified by the referencing Code Section. The rate of application of pressure shall be specified in the examination procedure and the pressurizing rate shall be sufficient to expedite the examination with minimum extraneous noise. Provisions shall be made for holding the pressure at designated hold points.

T-1222 Noise Reduction

External noise sources such as rain, foreign objects contacting the vessel, and pressurizing equipment noise must be below the system examination threshold.

T-1223 Sensors

T-1223.1 Sensor Frequency. Selection of sensor frequency shall be based on consideration of background noise, acoustic attenuation, and vessel configuration. Frequencies in the range of 100 kHz–400 kHz have been shown to be effective. (See Nonmandatory Appendix B.)

T-1223.2 Sensor Mounting. The location and spacing of the sensors are referenced in T-1243. The sensors shall be acoustically coupled using couplant specified in the written procedure. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated.

When examining austenitic stainless steels, titanium, or nickel alloys, the need to restrict chloride/fluoride ion content, total chlorine/fluorine content, and sulfur content in the couplant or other materials used on the vessel surface shall be considered and limits agreed upon between contracting parties.

The sensor shall be held in place utilizing methods of attachment, as specified in the written procedure.

The signal cable and preamplifier must be supported.

T-1223.3 Surface Contact. Sensors shall be mounted directly on the vessel surface, or on integral waveguides.

T-1224 Location of Acoustic Emission Sources

T-1224.1 Sources shall be located to the specified accuracy by multichannel source location, zone location, or both, as required by the referencing Code Section. All hits detected by the instrument shall be recorded and used for evaluation.

T-1224.2 Multichannel source location accuracy shall be within a maximum of 2 component wall thicknesses or 5% of the sensor spacing distance, whichever is greater.

T-1225 Procedure Requirements

Acoustic emission examination shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) material and configurations to be examined, including dimensions and product form;

(b) background noise measurements;

(c) sensor type, frequency, and Manufacturer;

(d) method of sensor attachment

(e) couplant;

(f) acoustic emission instrument type and filter frequency;

(g) sensor locations;

(h) method for selection of sensor locations;

(i) description of system calibration(s);

(j) data to be recorded and method of recording;

(k) post-examination vessel cleaning;

(l) report requirements; and

(m) qualification/certification of the examiner(s).

T-1230 EQUIPMENT AND SUPPLIES

(a) The AE system consists of sensors, signal processing, display, and recording equipment (see Appendix I).

(b) Data measurement and recording instrumentation shall be capable of measuring the following parameters from each AE hit on each channel: counts above system examination threshold, peak amplitude, arrival time, and Measured Area of the Rectified Signal Envelope (MARSE). Mixing or otherwise combining the acoustic emission signals of different sensors in a common preamplifier is not permitted except to overcome the effects of local shielding. (See Nonmandatory Appendix B.) The data acquisition system shall have sufficient channels to provide the sensor coverage defined in T-1243.4. Amplitude distribution, by channel, is required for source characterization. The instrumentation shall be capable of recording the measured acoustic emission data by hit and channel number.

(c) Time and pressure shall be measured and recorded as part of the AE data. The pressure shall be continuously monitored to an accuracy of ±2% of the maximum test pressure.

(1) Analog type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more than 4 times the test pressure.

(2) Digital type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

T-1240 APPLICATION REQUIREMENTS

T-1241 Equipment

(See T-1230 and Mandatory Appendix I.)

T-1242 System Calibration

(See Mandatory Appendix II.)

T-1243 Pre-Examination Measurements

T-1243.1 On-Site System Calibration. Prior to each vessel test or series of tests, the performance of each utilized channel of the AE instrument shall be checked by inserting a simulated AE signal at each main amplifier input.

A series of tests is that group of tests using the same examination system which is conducted at the same site within a period not exceeding 8 hr or the test duration, whichever is greater.

This device shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. As a minimum, on-site system calibration shall be able to verify system operation for threshold, counts, MARSE, and peak amplitude. Calibration values shall be within the range of values specified in Appendix I.

T-1243.2 Attenuation Characterization. An attenuation study is performed in order to determine sensor spacing. This study is performed with the test fluid in the vessel using a simulated AE source. For production line testing of identical vessels see Nonmandatory Appendix B.

The typical signal propagation losses shall be determined according to the following procedure: select a representative region of the vessel away from manways, nozzles, etc., mount a sensor, and strike a line out from the sensor at a distance of 10 ft (3 m) if possible. Break 0.3 mm (2H) leads next to the sensor and then at a 2 ft (0.6 m) interval along this line. The breaks shall be done with the lead at an angle of approximately 30 deg. to the surface and with a 0.1 in. (2.5 mm) lead extension.

T-1243.3 Sensor Location. Sensor locations on the vessel shall be determined by the vessel configuration and the maximum sensor spacing (see T-1243.4). A further consideration in locating sensors is the need to detect structural flaws at critical sections, e.g., welds, high stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. Additional consideration should be given to the possible attenuation effects of welds. See Nonmandatory Appendix B. Sensor location guidelines for zone location for typical vessel types are given in Nonmandatory Appendix A.

T-1243.4 Sensor Spacing

T-1243.4.1 Sensor Spacing for Zone Location. Sensors shall be located such that a lead break at any location in the examination area is detected by at least one sensor and have a measured amplitude not less than as specified by the referencing Code Section. The maximum sensor spacing shall be no greater than $1\frac{1}{2}$ times the threshold distance. The threshold distance is defined as the distance from a sensor at which a pencil-lead break on the vessel has a measured amplitude value equal to the evaluation threshold.

T-1243.4.2 Sensor Spacing for Multichannel Source Location Algorithms. Sensors shall be located such that a lead break at any location in the examination area is detected by at least the minimum number of sensors required for the algorithms.

T-1243.5 Systems Performance Check. A verification of sensor coupling and circuit continuity shall be performed following sensor mounting and system hookup and again immediately following the test. The peak amplitude response of each sensor to a repeatable simulated acoustic emission source at a specific distance from each sensor should be taken prior to and after the test. The measured peak amplitude should not vary more than 4 dB from the average of all the sensors. Any channel failing this check should be investigated and replaced or repaired as necessary. If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid system performance check shall be re-examined.

T-1244 Examination Procedure

T-1244.1 General Guidelines. The vessel is subjected to programmed increasing stress levels to a predetermined maximum while being monitored by sensors that detect acoustic emission caused by growing structural discontinuities.

T-1244.2 Background Noise. Extraneous noise must be identified, minimized, and recorded.

T-1244.2.1 Background Noise Check Prior to Loading. Acoustic emission monitoring of the vessel during intended examination conditions is required to identify and determine the level of spurious signals following the completion of the system performance check and prior to stressing the vessel. A recommended monitoring period is 15 min. If background noise is above the evaluation threshold, the source of the noise shall be eliminated or the examination terminated.

T-1244.2.2 Background Noise During Examination. In the AE examiner's analysis of examination results, background noise shall be noted and its effects on test results evaluated. Sources of background noise include:

(1) liquid splashing into a vessel;

(2) a pressurizing rate that is too high;

(3) pumps, motors, and other mechanical devices;

(4) electromagnetic interference; and

(5) environment (rain, wind, etc.).

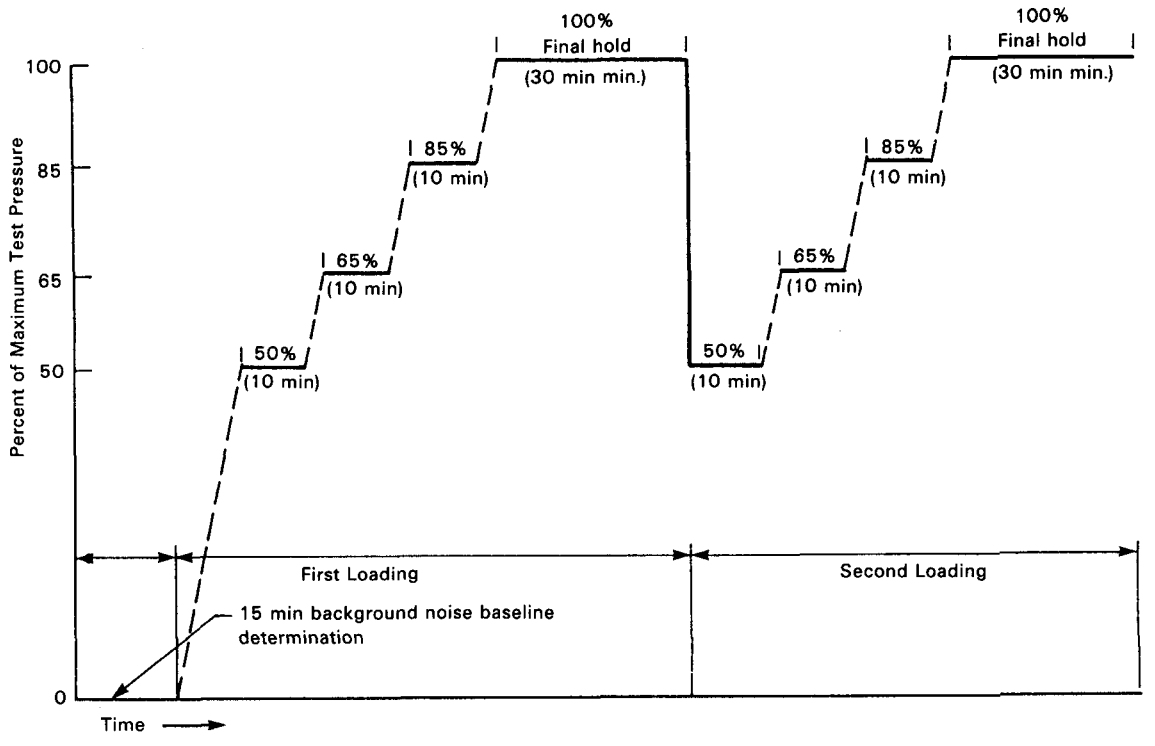
Leaks from the vessel such as valves, flanges, and safety relief devices can mask AE signals from the structure. Leaks must be eliminated prior to continuing the examination.

T-1244.3 Vessel Pressurization

T-1244.3.1 Rates of pressurization, pressurizing medium, and safety release devices shall be as specified by the referencing Code Section. The pressurization should be done at a rate that will expedite the test with a minimum of extraneous noise.

T-1244.3.2 Pressurization Sequence. The examination shall be done in accordance with the referencing Code Section. Pressure increments shall generally be to 50%, 65%, 85%, and 100% of maximum test pressure. Hold periods for each increment shall be 10 min and for the final hold period shall be at least 30 min. (See Fig. T-1244.3.2.) Normally, the pressure test will cause local yielding in regions of high secondary stress. Such local yielding is accompanied by acoustic emission which does not necessarily indicate discontinuities. Because of this, only large amplitude hits and hold period data are considered during the first loading of vessels without post-weld heat treatment (stress relief). If the first loading data indicates a possible discontinuity or is inconclusive, the vessel shall be repressurized from 50% to 100% of the test pressure with intermediate load holds at 50%, 65%, and 85%. Hold periods for the second pressurization shall be the same as for the original pressurization.

T-1244.3.3 Test Termination. Departure from a linear count or MARSE vs. load relationship should signal caution. If the AE count or MARSE rate increases rapidly with load, the vessel shall be unloaded and either the test terminated or the source of the emission determined and the safety of continued testing evaluated. A rapidly (exponentially) increasing count or MARSE rate may indicate uncontrolled, continuing damage indicative of impending failure.



GENERAL NOTE:
During loading, increases in pressure/load levels should not exceed 10% of the maximum test pressure in 2 min.

FIG. T-1244.3.2 AN EXAMPLE OF PRESSURE VESSEL TEST STRESSING SEQUENCE

T-1260 CALIBRATION

(See Mandatory Appendix II.)

T-1280 EVALUATION

T-1281 Evaluation Criteria

The AE criteria shown in Table T-1281 are set forth as one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria to be used shall be as specified in the referencing Code Section.

T-1290 DOCUMENTATION

T-1291 Written Report

The report shall include the following:

(a) complete identification of the vessel, including material type, method of fabrication, Manufacturer's name, and certificate number;

(b) vessel sketch of Manufacturer's drawing with dimensions and sensor locations;

(c) test fluid employed;

(d) test fluid temperature;

(e) test sequence load rate, hold times, and hold levels;

(f) attenuation characterization and results;

(g) record of system performance verifications;

(h) correlation of test data with the acceptance criteria;

(i) a sketch or Manufacturer's drawings showing the location of any zone not meeting the evaluation criteria;

(j) any unusual effects or observations during or prior to the test;

(k) date(s) of test(s);

(l) name(s) and qualifications of the test operator(s); and

(m) complete description of AE instrumentation including Manufacturer's name, model number, sensor type, instrument settings, calibration data, etc.

TABLE T-1281
AN EXAMPLE OF EVALUATION CRITERIA FOR ZONE LOCATION

	Emission During Load Hold	Count Rate	Number of Hits	Large Amplitude Hits	MARSE or Amplitude	Activity	Evaluation Threshold, dB
(First Loading) Pressure vessels without full postweld heat treatment	Not more than E_H hits beyond time T_H	Not applied	Not applied	Not more than E_A hits above a specified amplitude	MARSE or amplitudes do not increase with increasing load.	Activity does not increase with increasing load.	V_{TH}
Pressure vessels other than those covered above	Not more than E_H hits beyond time T_H	Less than N_T counts per sensor for a specified load increase	Not more than E_T hits above a specified amplitude	Not more than E_A hits above a specified amplitude	MARSE or amplitudes do not increase with increasing load.	Activity does not increase with increasing load.	V_{TH}

GENERAL NOTES:
(a) E_H, N_T, E_T, and E_A are specified acceptance criteria values specified by the referencing Code Section.
(b) V_{TH} is the specified evaluation threshold.
(c) T_H is the specified hold time.

T-1292 Record

(a) A permanent record AE data includes:

(1) AE hits above threshold vs time and/or pressure for zones of interest;

(2) total counts vs time and/or pressure; and

(3) written reports.

(b) The AE data shall be maintained with the records of the vessel.

ARTICLE 12
MANDATORY APPENDICES

APPENDIX I — INSTRUMENTATION PERFORMANCE REQUIREMENTS

I-1210 ACOUSTIC EMISSION SENSORS

I-1210.1 General. Acoustic emission sensors in the range of 100 kHz–400 kHz shall be temperature-stable over the range of intended use, and shall not exhibit sensitivity changes greater than 3 dB over this range as guaranteed by the Manufacturer. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice and/or differential (anticoincident) element design. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response.

I-1210.2 Sensor Characteristics. Sensors shall have a resonant response between 100 kHz–400 kHz. Minimum sensitivity shall be −80 dB referred to 1 volt/microbar, determined by face-to-face ultrasonic test.

NOTE: This method measures relative sensitivity of the sensor. Acoustic emission sensors used in the same test should not vary in peak sensitivity more than 3 dB from the average.

I-1220 SIGNAL CABLE

The signal cable from sensor to preamplifier shall not exceed 6 ft (1.8 m) in length and shall be shielded against electromagnetic interference.

I-1230 COUPLANT

Couplant selection shall provide consistent coupling efficiency during a test. Consideration should be given to testing time and the surface temperature of the vessel. The couplant and method of sensor attachment shall be specified in the written procedure.

I-1240 PREAMPLIFIER

The preamplifier shall be mounted in the vicinity of the sensor, or in the sensor housing. If the preamplifier is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. Frequency response shall not vary more than 3 dB over the operating frequency and temperature range of the sensors.

I-1250 FILTER

Filters shall be of the band pass or high pass type and shall provide a minimum of 24 dB/octave signal attenuation. Filters shall be located in preamplifier. Additional filters shall be incorporated into the processor. Filters shall insure that the principal processing frequency corresponds to the specified sensor frequency.

I-1260 POWER-SIGNAL CABLE

The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per 100 ft (30 m) of cable length. The recommended maximum cable length is 500 ft (150 m) to avoid excessive signal attenuation.

I-1270 POWER SUPPLY

A stable grounded electrical power supply, meeting the specifications of the instrumentation, shall be used.

I-1280 MAIN AMPLIFIER

The gain in the main amplifier shall be linear within 3 dB over the temperature range of 40°F—125°F (5°C—50°C).

I-1290 MAIN PROCESSOR

I-1291 General

The main processor(s) shall have processing circuits through which sensor data will be processed. It shall be capable of processing hits, counts, peak amplitudes, and MARSE on each channel.

(a) Threshold. The AE instrument used for examination shall have a threshold control accurate to within ±1 dB over its useful range.

(b) Counts. The AE counter circuit used for examination shall detect counts over a set threshold within an accuracy of ±5%.

(c) Hits. The AE instrument used for examination shall be capable of measuring, recording, and displaying a minimum of 20 hits/sec total for all channels for a minimum period of 10 sec and continuously measuring, recording, and displaying a minimum of 10 hits/sec total for all channels. The system shall display a warning if there is greater than a 5 sec lag between recording and display during high data rates.

(d) Peak Amplitude. The AE circuit used for examination shall measure the peak amplitude with an accuracy of ±2 dB.

(e) Energy. The AE circuit used for examination shall measure MARSE with an accuracy of ±5%. The usable dynamic range for energy shall be a minimum of 40 dB.

(f) Parametric Voltage. If parametric voltage is measured by the AE instrument, it should measure to an accuracy of 2% of full scale.

I-1292 Peak Amplitude Detection

Comparative calibration must be established per the requirements of Appendix II. Usable dynamic range shall be a minimum of 60 dB with 1 dB resolution over the frequency band width of 100 kHz to 400 kHz, and the temperature range of 40°F—125°F (5°C—50°C). Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values shall be stated in dB, and must be referenced to a fixed gain output of the system (sensor or preamplifier).

APPENDIX II — INSTRUMENT CALIBRATION AND CROSS-REFERENCING

II-1210 MANUFACTURER'S CALIBRATION

Acoustic emission system components will be provided from the Manufacturer with certification of performance specifications and tolerances.

II-1211 Annual Calibration

The instrument shall have an annual comprehensive calibration following the guidelines provided by the Manufacturer using calibration instrumentation meeting the requirements of a recognized national standard.

II-1220 INSTRUMENT CROSS-REFERENCING

The performance and threshold definitions vary for different types of AE instrumentation. Parameters such as counts, amplitude, energy, etc., vary from Manufacturer to Manufacturer and from model to model by the same Manufacturer. This section of appendix describes techniques for generating common baseline levels for the different types of instrumentation.

The procedures are intended for baseline instrument calibration at 60°F to 80°F (16°C to 27°C). For field use, small portable signal generators and calibration transducers can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

II-1221 Sensor Characterization

Threshold of acoustic emission detectability is an amplitude value. All sensors shall be furnished with documented performance data. Such data shall be traceable to NBS standards. A technique for measuring threshold of detectability is described in Article XI, Appendix II.

APPENDIX III — GLOSSARY OF TERMS FOR ACOUSTIC EMISSION EXAMINATION OF METAL PRESSURE VESSELS

III-1210 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms relating to metal pressure vessel examination with acoustic emission.

III-1220 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 defines the terms that are used in conjunction with this Article.

(c) For general terms, such as *Interpretation, Flaw, Discontinuity, Evaluation*, etc., refer to Article 1, Mandatory Appendix I.

(d) In addition to those terms listed in SE-1316, the terms listed in II-1230 are also applicable.

III-1230 REQUIREMENTS

The following Code terms are used in conjunction with this Article:

dB scale — a relative logarithmic scale of signal amplitude defined by dB V = 20 log V^{in}/V^{out}. The reference voltage is defined as 1 volt out of the sensor and V is measured amplitude in volts.

electronic waveform generator — a device which can repeatably induce a transient signal into an acoustic emission processor for the purpose of checking, verifying, and calibrating the instrument

measured area of the rectified signal envelope — a measurement of the area under the envelope of the rectified linear voltage time signal from the sensor

multi-channel source location — a source location technique which relies on stress waves from a single source producing hits at more than one sensor. Position of the source is determined by mathematical algorithms using difference in time of arrival

simulated AE source — a device which can repeatedly induce a transient elastic stress wave into the structure

threshold of detectability — a peak amplitude measurement used for cross calibration of instrumentation from different vendors

zone — the area surrounding a sensor from which AE sources can be detected

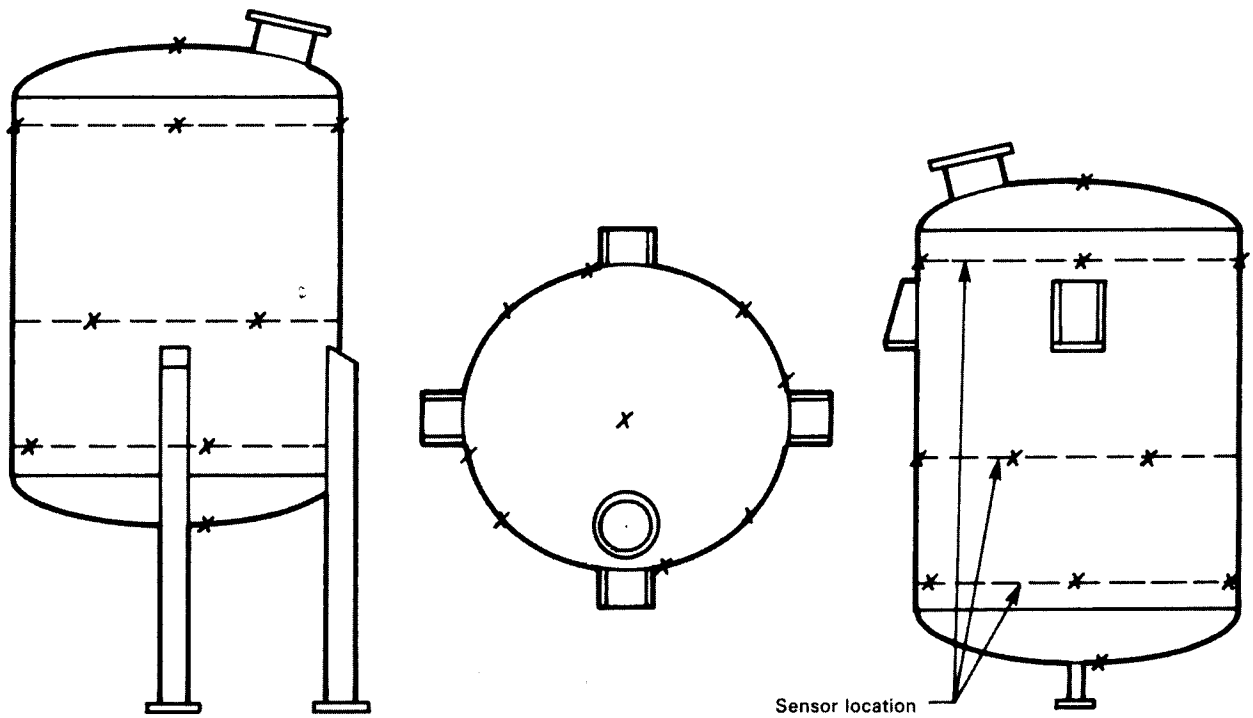
zone location — a method of locating the approximate source of emission

ARTICLE 12
NONMANDATORY APPENDICES

Appendix A begins on the next page.

APPENDIX A
SENSOR PLACEMENT GUIDELINES

CASE 1 — VERTICAL PRESSURE VESSEL DISHED HEADS, LUG OR LEG SUPPORTED

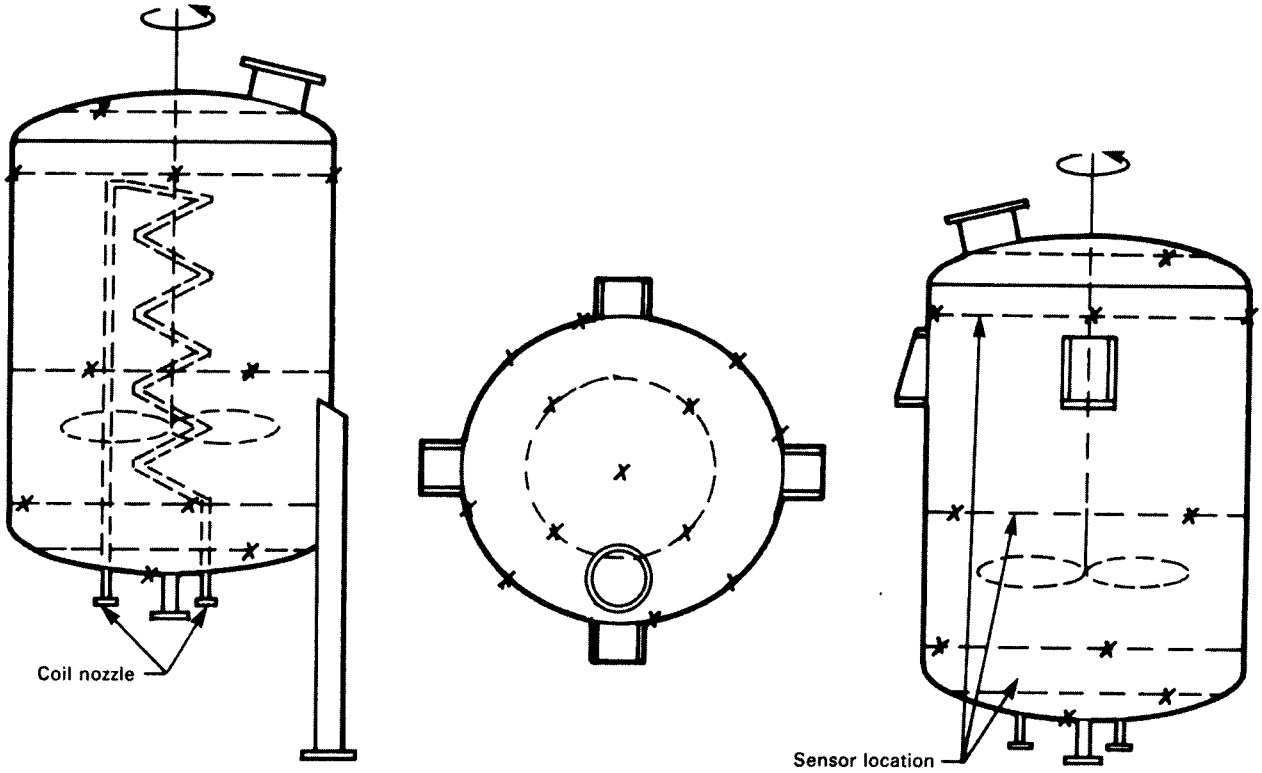


Leg Supported

Lug Supported

GUIDELINES:
(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Additional rows of sensors may be required.

CASE 2 — VERTICAL PRESSURE VESSEL DISHED HEADS, AGITATED, BAFFLED LUG, OR LEG SUPPORT



Leg Supported

Lug Supported

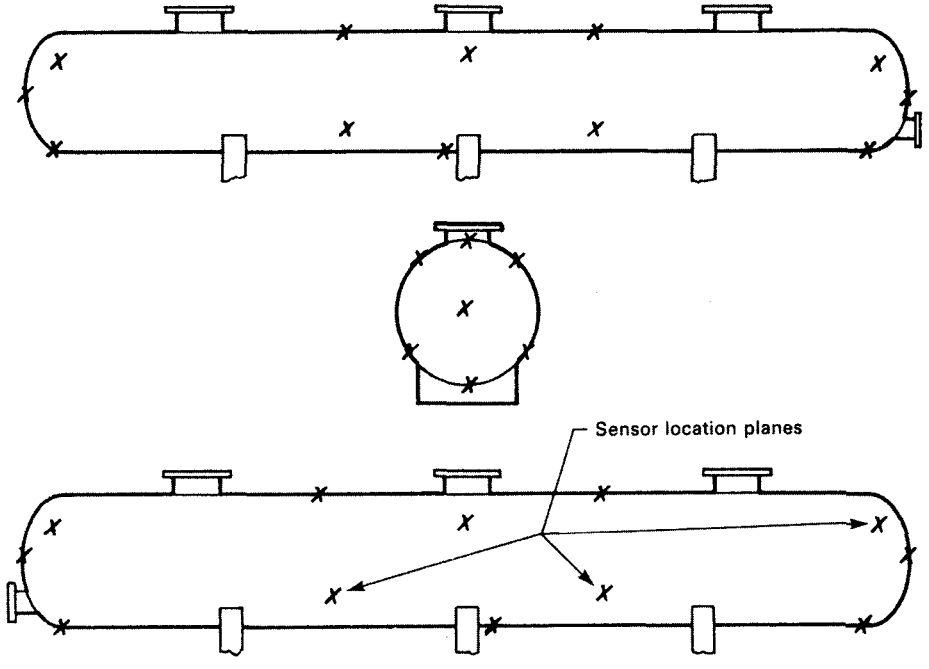
GUIDELINES:

(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).

(2) Sensors may be located on outlet to detect defects in coil.

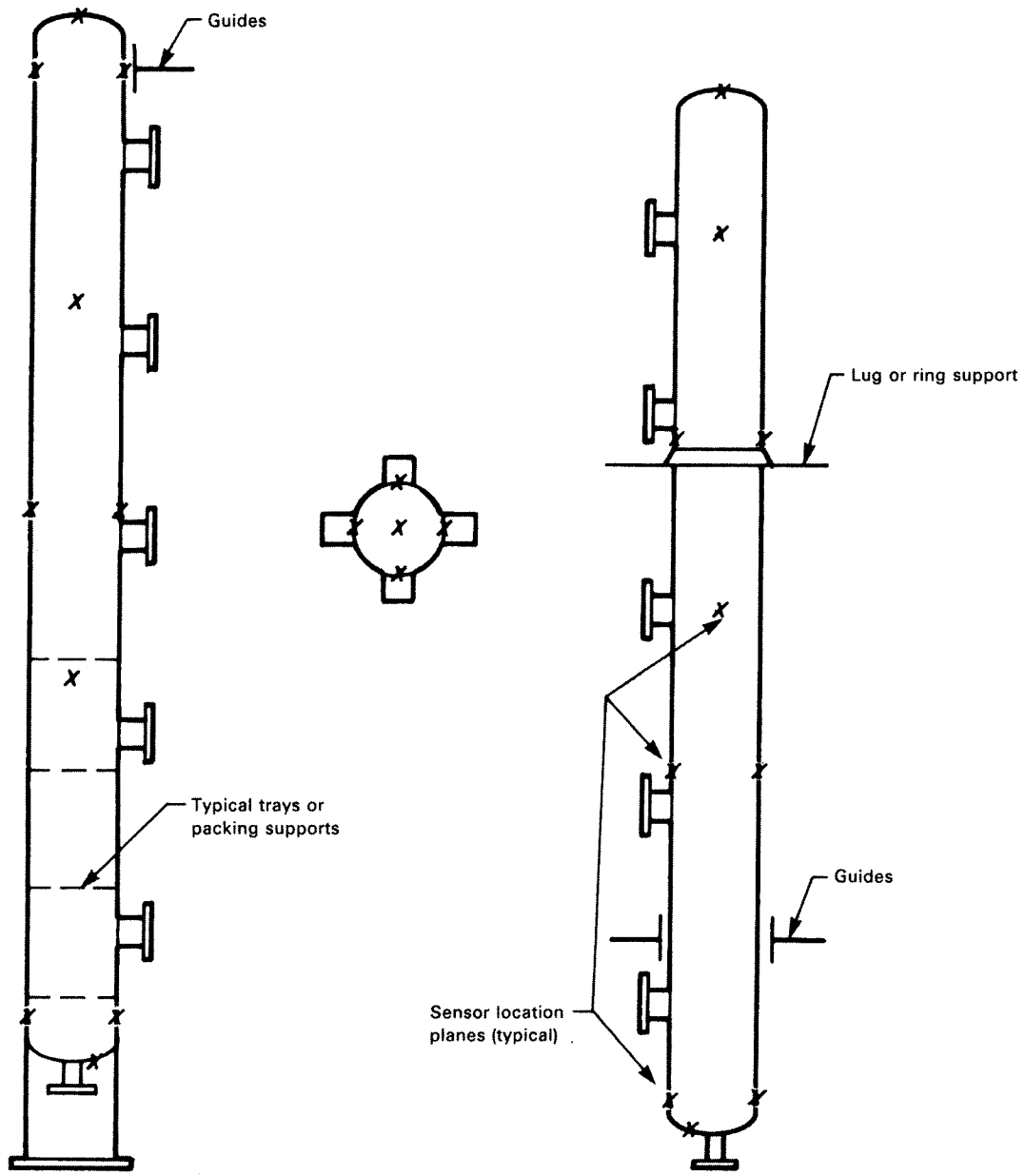
(3) Additional rows of sensors may be required.

CASE 3 — HORIZONTAL PRESSURE VESSEL DISHED HEADS, SADDLE SUPPORTED



GUIDELINES:
(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).
(2) Additional rows of sensors may be required.

CASE 4 — VERTICAL PRESSURE VESSEL PACKED OR TRAYED COLUMN DISHED HEADS, LUG OR SKIRT SUPPORTED



Skirt Supported

Lug or Ring Supported

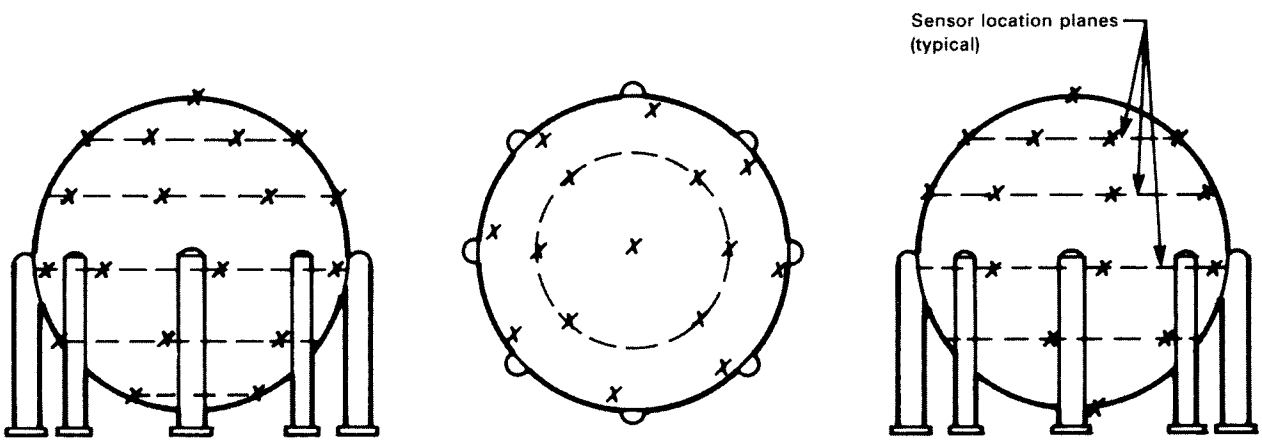
GUIDELINES:

(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).

(2) Special areas may require additional sensors.

(3) Additional rows of sensors may be required.

CASE 5 — SPHERICAL PRESSURE VESSEL, LEG SUPPORTED



Left-Side Elevation

Plan View — Top

Right-Side Elevation

GUIDELINES:

(1) *X* denotes sensor locations (maximum distance between adjacent sensors shall be determined from vessel attenuation characterization).

(2) Additional sensors may be required.

ARTICLE 12
NONMANDATORY APPENDICES

APPENDIX B — SUPPLEMENTAL INFORMATION FOR CONDUCTING ACOUSTIC EMISSION EXAMINATIONS

B-10 FREQUENCY SELECTION

The frequency band of 100 kHz–200 kHz is the lowest frequency band that should be considered for general AE pressure vessel examination. Higher frequency bands may be considered if background noise cannot be eliminated. If a higher frequency band is used the following items must be considered.

(a) Attenuation characteristics will change.

(b) Sensor spacings will decrease and more sensors will be required to adequately cover the evaluation area.

(c) Instrumentation performance requirements described in Appendix I must be adjusted to the higher frequency band.

(d) Instrumentation calibration described in Appendix II must be performed at the higher frequency band.

(e) Alternate evaluation/acceptance criteria must be obtained from the referencing Code Section.

B-20 COMBINING MORE THAN ONE SENSOR IN A SINGLE CHANNEL

Two or more sensors (with preamplifiers) may be plugged into a single channel to overcome the effects of local shielding in a region of the vessel. One specific example of this is the use of several sensors (with preamplifiers around a manway or nozzle).

B-30 ATTENUATIVE WELDS

Some have been shown to be highly attenuative to non-surface waves. This situation predominantly affects multichannel source location algorithms. This situation can be identified by modifying the attenuation characterization procedure to produce a stress wave which does not contain surface waves traveling across the weld.

B-40 PRODUCTION LINE TESTING OF IDENTICAL VESSELS

For situations which involve repeated tests of identical vessels where there is no change in the essential variables such as material, thickness, product form and type, the requirement for attenuation characterization on each vessel is waived.

ARTICLE 13
CONTINUOUS ACOUSTIC EMISSION MONITORING

T-1310 SCOPE

This Article describes requirements to be used during continuous acoustic emission (AE) monitoring of metal or non-metal pressure boundary components used for either nuclear or non-nuclear service. Monitoring may be performed as a function of load, pressure, temperature, and/or time.

When AE monitoring in accordance with this Article is required, the referencing Code Section should specify the following:

(a) personnel qualification/certification requirements

(b) extent of examination and/or area(s)/volume(s) to be monitored

(c) duration of monitoring period

(d) acceptance/evaluation criteria

(e) reports and records requirements

When this Article is specified by a referencing Code section, the technical requirements described herein shall be used together with Article 1, General Requirements. Definitions of terms used in this Article are in Mandatory Appendix VII of this Article.

Generic requirements for continuous acoustic emission monitoring of pressure boundary components during operation are addressed within this Article. Supplemental requirements for specific applications such as nuclear components, non-metallic components, monitoring at elevated temperatures, limited zone monitoring, lead detection, etc., are provided in the Mandatory Appendices to this Article.

T-1311 References

SE-650, Standard Guide for Mounting Piezoelectric Acoustic Emission Sensors

SE-976, Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

SE-1211, Standard Practice for Leak Detection and Location using Surface-Mounted Acoustic Emission Sensors

SE-1316, Standard Terminology for Nondestructive Examinations

SE-1419, Standard Test Method for Examination of Seamless, Gas-Filled Pressure Vessels Using Acoustic Emission

ASTM E 750-88 (1993), Standard Practice for Characterizing Acoustic Emission Instrumentation

ASTM E 1067-89 (1991), Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels

ASTM E 1118-89, Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

ASTM E 1139-92, Standard Practice for Continuous Monitoring of Acoustic Emission from Metal Pressure Boundaries

T-1320 GENERAL

T-1321 Monitoring Objectives

The objectives of AE examination are to detect, locate, and characterize AE sources, and interpret the AE response signals to evaluate significance relative to pressure boundary integrity. These AE sources are limited to those activated during normal plant system operation, i.e., no special stimulus is applied exclusively to produce AE. In the context of this Article, normal system operation may include routine pressure tests performed during plant system shutdown.

T-1322 Relevant Indications

All relevant indications detected during AE monitoring should be evaluated by other methods of nondestructive examination.

T-1323 Personnel Qualification

T-1323.1 Procedures and Equipment Installation. All procedures used for qualifying, calibrating, installing, and operating the AE equipment, and for data analysis activities, shall be approved by a certified AE Level III.

Installation, calibration, and checkout of the AE equipment shall be performed under the direction of a certified AE Level III.

T-1323.2 AE System Operation. Routing operation of the AE system for collection and interpretation of data may be performed by competent personnel that are not necessarily AE specialists. However, AE system operation and data interpretation shall be verified by a certified AE Level III on approximately monthly intervals or more often if the system appears to be malfunctioning, relevant signals are detected, or an abrupt change in the rate of AE signals is observed.

T-1324 Component Stressing

Several means of stressing are applicable to AE examination including startup, continuous and cyclic operation, and shut-down of operating plant systems and components, as well as pressure tests of non-operating plant systems. Stress may be induced by either pressure or thermal gradients or a combination of both. It is the intent of this Article to describe examination techniques that are applicable during normal operation of pressurized plant system or component. During startup, the pressurizing rate should be sufficient to facilitate the examination with minimum extraneous noise. If appropriate, provisions should be made for maintaining the pressure at designated hold points. Advice on the use of compressed gas as a pressurizing medium is contained in SE-1419.

T-1325 Noise Interference

Noise sources that interfere with AE signal detection should be controlled to the extent possible. For continuous monitoring, it may be necessary to accommodate background noise by monitoring at high frequencies, shielding open AE system leads, using differential sensors, and using special data filtering techniques to reduce noise interference.

T-1326 Coordination With Plant System Owner/Operator

Due to operational considerations unique to the AE method, close coordination between the AE monitor operator and the owner/operator of the plant should be established and maintained. Provisions for this coordination function should be described in the written procedures submited for approval prior to initiation of AE monitoring activities.

T-1327 Source Location and Sensor Mounting

Sources shall be located with the specified accuracy by multichannel sensor array, zone location, or both. As required by the referencing Code section, requirements for sensor mounting, placement, and spacing are further defined in the applicable Appendix.

T-1330 EQUIPMENT

T-1331 General

The AE system will consist of sensors, preamplifiers, amplifiers, filters, signal processors, and a data storage device together with interconnecting cables. Simulated AE source(s) and auxiliary equipment such as pressure and temperature inputs are also required. The AE monitoring system shall provide the functional capabilities shown in Fig. T-1331.

T-1332 Sensors

Sensors shall be one of two general types — those mounted directly on the surface of the component being monitored and those that are separated from the surface of the component by a connecting waveguide. Sensors shall be acoustically coupled to the surface of the component being monitored and be arranged in arrays capable of providing AE signal detection and source location to the required accuracy. Selection of sensor type shall be based on the application; i.e., low or high temperature, nuclear or non-nuclear, etc. The sensor selected for a specific application shall be identified in the procedure prepared for that application. The sensor system (i.e., sensors, preamplifiers, and connecting cables) used to detect AE shall limit electromagnetic interference to a level not exceeding 0.7 V peak after 90 dB amplification.

T-1332.1 Sensor Response Frequency. For each application, selection of the sensor response frequency shall be based on a characterization of background noise in terms of amplitude vs. frequency. The lowest frequency compatible with avoiding interference from background noise should be used to maximize sensitivity of AE signals and minimize signal attenuation.

T-1332.2 Differential and Tuned Sensors. Two sensor designs have been effective in overcoming noise interference problems. One is a differential sensor that operates to cancel out electrical transients entering the system through the sensor. The other is an inductively tuned sensor that operates to shape the sensor response around a selected frequency; i.e., inductive tuning allows discrimination against frequencies on either side of a selected response frequency as shown in Fig. T-1332.2. These sensor designs may be used separately or together.

T-1332.3 Sensor Mounting. Sensors shall be mounted to the component surface using two basic methods. One is to bond the sensor directly to the surface

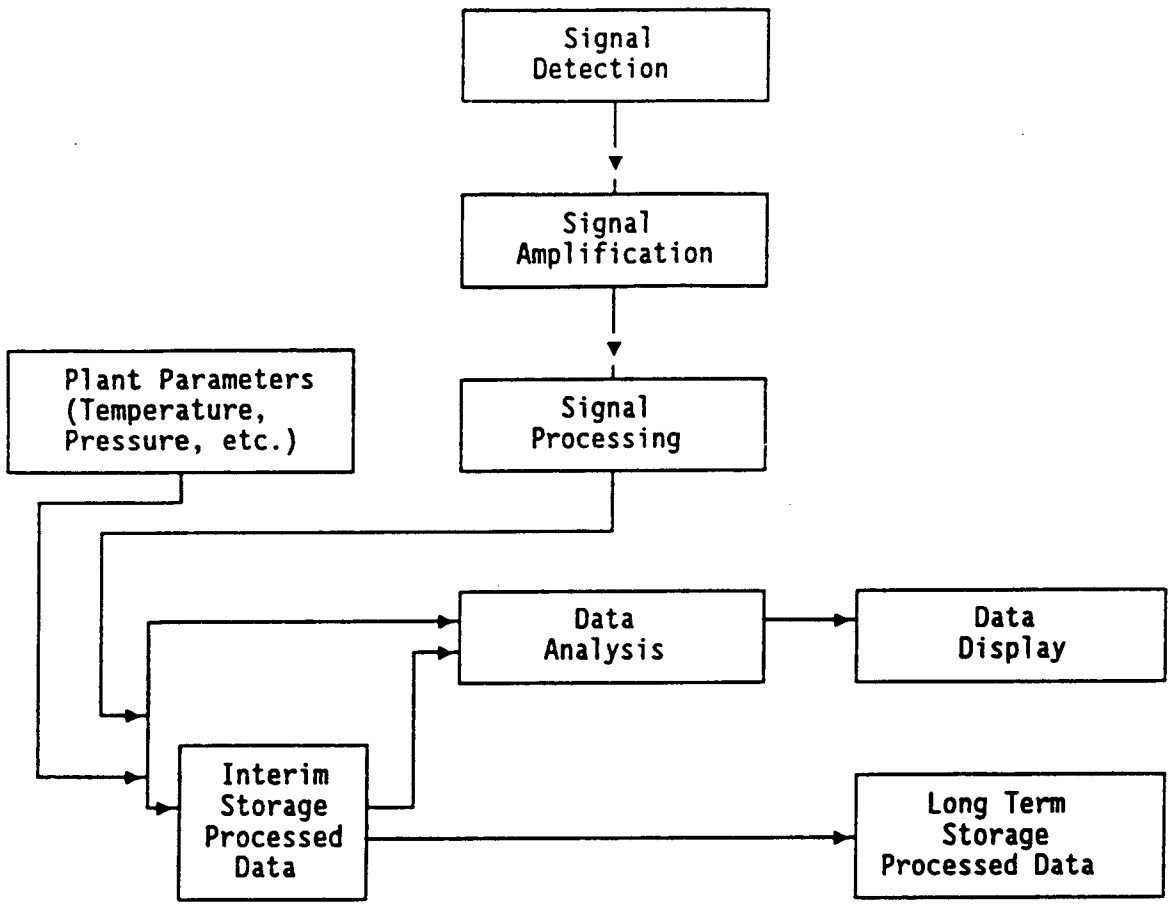


FIG. T-1331 FUNCTIONAL FLOW DIAGRAM — CONTINUOUS AE MONITORING SYSTEM

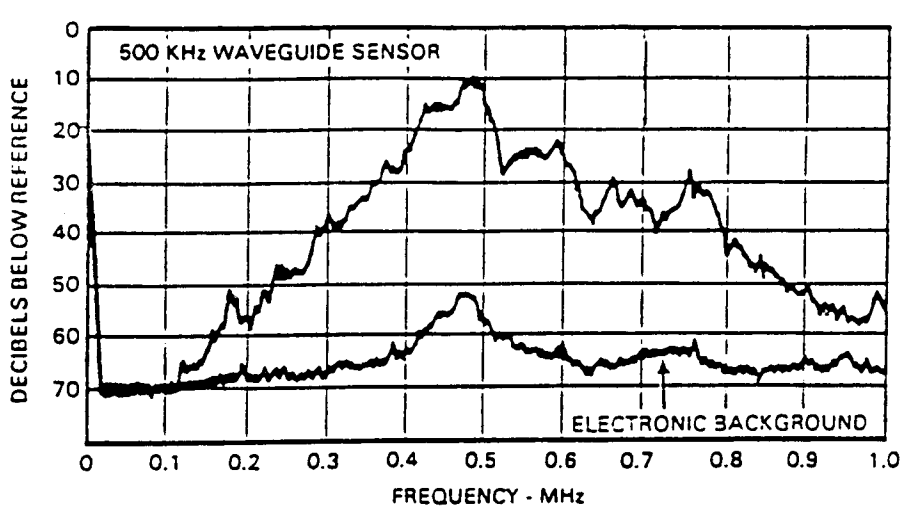


FIG. T-1332.2 RESPONSE OF A WAVEGUIDE AE SENSOR INDUCTIVELY TUNED TO 500 kHz

with an adhesive. Temperature and vibration can adversely affect the bond between the sensor and the surface being monitored. Also, the chemical content of the adhesive shall be checked to assure that it is not deleterious to the surface of the component.

The second method for mounting a sensor employs pressure coupling using either a strap or a magnetic mount. A thin, soft metal interface layer between the sensor and the surface is often effective for achieving acoustic coupling with minimal pressure. In the case of waveguide sensors, the tip of the waveguide may be shaped to reduce the required force to maintain acoustic coupling.

T-1333 Signal Cables

Coaxial cables shall be used to conduct the AE signals from the sensors to the monitoring instrument (monitor). Whenever a protective barrier or containment structure must be penetrated using a bulkhead fitting or penetration plug to transmit signals from the sensor to the monitor, extreme care must be taken to avoid incurring excessive signal loss or noise. When the coaxial (signal) cables are used to supply DC power to the preamplifiers/line drivers, they should be terminated with the appropriate characteristic impedance.

T-1334 Amplifiers

At least one preamplifier shall be used with each sensor to amplify the AE signals for transmission to the monitor. Where long signal cables are required, a preamplifier and line driver between the sensor and the monitor may be needed.

With the high signal amplification required to detect AE signals, the internal noise of the preamplifiers must be minimized to avoid interference with AE signal detection. The frequency response band of the amplifiers shall be matched to the response profile determined for the AE sensors.

T-1335 AE Monitor

The AE monitor shall include a post amplifier, a signal identification function, and a signal processing module for each signal channel. The monitor shall also include a video display function that can be used at the operator's discretion to display AE data as well as a data storage capability suitable for long term, nonvolatile data storage. A data analysis function may be integral with the AE monitor or be a separate function that draws from the stored AE data.

The post amplifier shall meet the requirements of T-1334. The AE monitor shall be capable of processing and recording incoming data at a rate of at least 50 hits/sec for all channels simultaneously for an indefinite time period and at a rate of at least 100 hits/sec for all channels simultaneously for any 15 sec period.

T-1335.1 AE Signal Identification. A real-time signal discrimination function to process incoming signals and identify relevant AE signals shall be included. The discrimination function may either exclude all signals not identified as AE from crack growth, or flag those signals identified as crack growth AE while accepting all signals above the voltage threshold.

T-1335.2 Signal Processing. The dynamic range of the signal processor shall be at least 36 dB for each parameter being measured. The signal processor shall be controlled by voltage threshold circuits that limit accepted data to signals that exceed the voltage amplitude threshold. The voltage threshold shall be determined on the basis of the background noise.

Signal parameters to be measured shall include AE hit count, total number of signal hits at each sensor, signal peak amplitude, time for threshold crossing to signal peak, measured area under the rectified signal envelope (MARSE) in V-secs, and difference in time of signal arrival (δt) at all sensors in a sensor array used for AE source location. In addition to the AE signal features above, clock time, date, and the value of plant parameters (internal pressure, temperature, etc., that can be identified as significant to crack growth) associated with the time of signal detection shall be recorded for each signal. The signal processor section shall also measure the overall RMS background signal level for each sensing channel for leak detection purposes.

T-1335.3 Data Storage. Data storage shall be nonvolatile and capable of storing the data described in T-1335.2 continuously over time periods of several weeks to several months depending on the application. One recording method that has proven satisfactory for continuous monitoring is a digital tape recorder using $\frac{1}{4}$ in. (6 mm), 16 track digital tape cartridges.

T-1335.4 Data Analysis and Display. The data analysis function of the AE monitor shall determine the location of AE sources as specified in the procedure (T-1350). Location accuracies within one wall thickness of the pressure boundary or 5% of the minimum sensor spacing, whichever is greater, are typical for metal components.

The data anaylsis function shall be capable of providing a display and plot of selected AE information (e.g., AE events, crack growth AE from a given source area, AE energy) vs. plant system parameters and vs. time for correlation evaluations. Data analysis shall also provide

continuous assessment of RMS signal level information derived from the signal measurement section.

The AE monitor system shall provide a means of presenting analyzed data; either a computer printout or a printout in conjunction with a video display. When the AE rate from an array exceeds the rate specified in the written procedure, the system shall activate an operator alert and identify the sensor array producing the high AE rate.

T-1340 REQUIREMENTS

T-1341 Equipment Qualification

Acceptable performance, including dynamic range, of the complete AE monitor (without sensors) shall be verified using an electronic waveform generator prior to installation. Sinusoidal burst signals from the waveform generator shall be input of each preamplifier to verify that the signal amplification, data processing functions, data processing rate, and data analysis, display, and storage meet the requirements of this Article. (NOTE: AE signal source location performance is tested under T-1362.1.) With the AE monitor gain set at operating level, the system shall be evaluated using input signals that will test both the low and high ends of the dynamic range of the AE monitor system. Signal frequencies shall include samples within the range of intended use.

T-1342 Sensor Qualification

T-1342.1 Sensor Sensitivity and Frequency Response. Each sensor shall produce a minimum signal of 0.1 mV_{peak} referred to the sensor output at the selected monitoring frequency when mounted on a calibration block and excited with a helium gas jet as described in SE-976. Appropriate calibration blocks are identified in the Appendices as a function of specific applications. Helium gas excitation shall be performed using a 30 psi (200 kPa) helium source directed onto the surface of the calibration block through a #18 hypodermic needle held perpendicular to the calibration block surface. The needle tip shall be $\frac{1}{8}$ in. (3 mm) above the surface of the block and $1\frac{1}{2}$ in. (38 mm) from the mounted sensor. The process may also be used to verify the sensor response profile in terms of frequency to assure that the response roll-off on either side of the selected monitoring frequency is acceptable.

An optional technique for determining the reproducibility of AE sensor response is referred to as the "Pencil Lead Break" technique, which is described in SE-976.

T-1342.2 Uniformity of Sensor Sensitivity. The sensitivity of each sensor shall be evaluated by mounting it on a calibration block as it will be mounted on the plant component and measuring its response to the energy produced by fracturing a 0.3 mm, 2H pencil lead against the surface of the block in accordance with SE-976 at a point 4 in. (100 mm) from the center of the sensor. When performing this evaluation, it is useful to use a 40 dB preamplifier with the sensor to produce and adequate output signal for accurate measurement. The peak response of each sensor to the simulated AE signal shall not vary more than 3 dB from the average for all sensors at the selected monitoring frequency.

T-1343 Signal Pattern Recognition

If AE signal pattern recognition is used, this function shall be demonstrated and qualified as follows:

(a) Assemble the AE monitor including two representative sensors mounted on a calibration block with the same acoustic coupling process to be used for monitoring. The sensors shall be excited ten times by each of the following three methods:

(1) Fracture a 0.3 mm, 2H pencil lead against the surface of the block in accordance with SE-976.

(2) Strike the surface of the block with $\frac{1}{4}$ in. (6 mm) diameter steel ball dropped from a uniform height sufficient to produce a response from the sensors that does not saturate the AE monitor.

(3) Inject a multi-cycle (five cycles minimum) burst signal into the block with a transducer and waveform generator.

(b) The pattern recognition function shall identify at least 8 out of 10 lead fracture signals as AE crack growth signals and at least 8 out 10 of each other type signals as signals not associated with crack growth.

T-1344 Material Attenuation/Characterization

Prior to installation of AE system for monitoring plant components, the acoustic signal attenuation in the material shall be characterized. This is necessary for determining the sensor spacing for effective AE detection. Attenuation measurements shall be made at the frequency selected for AE monitoring and shall include both surface and bulk wave propagation. The attenuation measurements should be performed with the material temperature within ±200°F (±110°C) of the expected temperature during actual component monitoring.

T-1345 Background Noise

The AE system response to background noise shall be characterized. With 90 dB amplification, the AE system signal level response to continuous process background noise shall not exceed 1.5 V_{peak} output. This shall be

achieved by restricting the frequency response of the sensor system. Reducing sensitivity is not acceptable.

T-1346 Qualification Records

Documentation of the equipment qualification process shall include the following:

(a) a copy of the equipment qualification procedure

(b) personnel certificate records

(c) description of the AE equipment and qualification equipment used

(d) quantitative results of the qualification

(e) signature of the AE Level III responsible for the qualification

(f) date of the qualification

Equipment qualification records shall be retained as part of the monitoring application records.

T-1347 Sensor Installation

T-1347.1 Coupling. Adequate acoustic coupling between the sensor and the component surface shall be verified as the sensors are mounted. This can be done by lightly tapping the surface or by breaking a pencil lead against the component surface while observing the sensor output. Guidance for sensor mounting is provided in SE-650 and in T-1332.3. The use of drilled and tapped holes in the component is generally not acceptable.

T-1347.2 Array Spacing. A sufficient number of sensors shall be located on the component in a multi-source array(s) to provide for AE signal detection and source location. Each sensor shall produce an output of at least 0.3 mV_{peak} when a 0.3 mm, 2H pencil lead is broken against the bare surface of the component at the most remote location that the sensor is expected to monitor. When a location algorithm is used, the location of each lead break shall be surrounded with a material (mastic or putty) to absorb surface waves. A 0.1 in. (2.5 mm) lead extension shall be broken at an angle of approximately 30 deg. to the component surface.

T-1347.3 Functional Verification. One or more acoustic signal sources, with an output frequency range of 100 to 700 kHz shall be installed within the monitoring zone of each sensor array for the purpose of periodically testing the functional integrity of the sensors during monitoring. This is not intended to provide a precise sensor calibration but rather a qualitative sensitivity check. It shall be possible to activate the acoustic signal source(s) from the AE monitor location.

T-1348 Signal Lead Installation

The coaxial cable and other leads used to connect the sensors to the AE monitor shall be demonstrated to be capable of withstanding extended exposure to hostile environments as required to perform the monitoring activities.

T-1349 AE Monitor Installation

The AE monitor shall be located in a clean, controlled environment suitable for long-term operation of a computer system. The electronic instrumentation (preamplifiers and AE monitor components) shall be located in an area that is maintained at temperatures not exceeding 125°F (50°C).

T-1350 PROCEDURE REQUIREMENTS

AE monitoring activities shall be performed in accordance with a written procedure. Each procedure shall include at least the following information, as applicable:

(a) Components to be monitored include dimension, materials of construction, operating environment, and duration of monitoring

(b) a description of the AE system to be used and its capabilities in terms of the functional requirements for the intended application

(c) AE system calibration and qualification requirements

(d) number, location, and mounting requirements for AE sensors

(e) interval and acceptable performance during the AE system functional check (T-1373.2)

(f) data recording processes and data to be recorded

(g) data analysis, interpretation, and evaluation criteria

(h) supplemental NDE requirements

(i) personnel qualification/certification requirements

(j) reporting and record retention requirements

The procedure described below need not be large documents, and preprinted blank forms (technique sheets) may be utilized provided they contain the required information.

T-1351 AE System Operation

A written precedure describing operation of the AE system shall be prepared, approved by the cognizant AE Level III, and made available to the personnel responsible for operating the AE system. Each procedure shall be tailored to recognize and accommodate unique requirements associated with the plant system or component being monitored.

T-1352 Data Processing, Interpretation, and Evaluation

A written procedure for processing, interpreting, and evaluating the AE data shall be prepared and approved

by the cognizant AE Level III. This procedure shall be made available to the personnel responsible for operating the AE system, the personnel responsible for AE data interpretation and evaluation, and a representative of the owner of the plant system being monitored. This procedure shall be tailored to recognize and accommodate unique requirements associated with the plant system or component being monitored.

T-1353 Data Recording and Storage

Specific requirements for recording, retention, and storage of the AE and other pertinent data shall be prepared for approval by representatives of the plant system owner or operator. These requirements shall be made available to the personnel responsible for data recording and storage.

T-1360 CALIBRATION

T-1361 Sensors

The frequency response for each AE channel shall be measured with the sensors installed on a plant pressure boundary component. Sensor response shall be measured at the output of the preamplifier using a spectrum analyzer. The excitation source shall be a helium gas jet directed onto the component surface from a nominal 30 psi (200 kPa) source through a #18 hypodermic needle held perpendicular to the component surface at a standoff distance of $\frac{1}{8}$ in. (3 mm) located $1\frac{1}{2}$ in. (38 mm) from the mounted sensor. The gas shall not impinge on the sensor or the waveguide. AE sensor peak response to the gas jet excitation at the monitoring frequency shall be at least 0.1 mV_{peak} referred to the output of the sensor. Any AE sensor showing less than 0.1 mV_{peak} output shall be reinstalled or replaced, as necessary, to achieve the required sensitivity.

An optional technique for determining the reproducibility of AE sensor response is referred to as the "Pencil Lead Break" technique which is described in SE-976.

T-1362 Complete AE Monitor System

T-1362.1 Detection and Source Location. The signal detection and source location accuracy for each sensor array shall be measured using simulated AE signals injected on the component surface at not less than 10 preselected points within the array monitoring field. These simulated AE signals shall be generated by breaking 2H pencil leads (0.3 or 0.5 mm diameter) against the component surface at the prescribed points. The pencil leads shall be broken at an angle of approximately 30 deg. to the surface using a 0.1 in. (2.5 mm) pencil lead extension (see SE-976). The location of each pencil lead break shall be surrounded with a material (mastic or putty) to absorb surface waves. Location accuracies within one wall thickness at the AE source location or 5% of the minimum sensor array spacing distance, whichever is greater, are typical.

T-1362.2 Function Verification. Response of the AE system to the acoustic signal source described in T-1347.3 shall be measured and recorded for reference during later checks of the AE system.

T-1363 Calibration Intervals

The installed AE monitor system shall be recalibrated in accordance with T-1360 at the end of each plant operating cycle. This is defined more explicitly in the Appendices describing requirements for each AE monitoring application.

T-1364 Calibration Records

Documentation of the installed system calibration shall include the following:

(a) a copy of the calibration procedure(s)

(b) personnel certification records

(c) description of the AE equipment and the calibration equipment used

(d) quantitative results of the calibration

(e) signature of the individual responsible for the calibration

(f) date(s) of the calibration(s).

Retention of the calibration records shall be in accordance with T-1393.

T-1370 EXAMINATION

The AE monitor system shall comply with the requirements of approved procedures (T-1350) that have been accepted by the plant owner/operator.

T-1371 Personnel

Operation of the AE system for routine collection and interpretation of data may be performed by a competent individual not necessarily specialized in AE who has received training and has at least limited AE Level II certification. However, AE system operation and data interpretation shall be verified by a certified AE Level III on a monthly interval or sooner if the system appears to be malfunctioning or there is an abrupt change in the rate of AE data accumulation.

T-1372 Plant Startup

During plant startup, AE rate and source location information shall be evaluated at least once per shift for indications of flaw growth. The RMS signal level shall also be evaluated for indications of pressure boundary leaks.

T-1373 Plant Steady-State Operation

T-1373.1 Data Evaluation Interval AE data shall be evaluated at least weekly during normal plant operation. When a sustained AE activity rate from one or more sensors occurs or when a consistent clustering of AE signals accepted by the signal identification analyzer and which cluster in one source location of AE signals is concentrated within a diameter of three times the wall thickness of the component or 10% of the minimum sensor spacing distance in the array, whichever is greater. Also refer to Appendices II and III.

T-1373.2 AE System Functional Check. AE system response to the installed acoustic signal source shall be evaluated periodically as specified in the procedure. Deterioration of sensitivity exceeding 4 dB for any channel shall be recorded and the affected component shall be replaced at the earliest opportunity.

T-1374 Nuclear Components

Specific and supplemental examination requirements for nuclear components are specified in Appendix I.

T-1375 Non-Nuclear Metal Components

Specific and supplemental examination requirements for non-nuclear metal components are specified in Appendix II.

T-1376 Non-Metallic Components

Specific and supplemental examination for non-metallic components are specified in Appendix III.

T-1377 Limited Zone Monitoring

Specific and supplemental examination requirements for limited zone monitoring are specified in Appendix IV.

T-1378 Hostile Environment Applications

Specific and supplemental examination requirements for hostile environment applications are specified in Appendix V.

T-1379 Leak Detection Applications

Specific and supplemental examination requirements for leak detection applications are specified in Appendix VI.

T-1380 EVALUATION/RESULTS

T-1381 Data Processing, Interpretation, and Evaluation

Data processing, interpretation, and evaluation shall be in accordance with the written procedure (T-1350) for that specific application and the applicable Mandatory Appendices. The methodology and criteria will vary substantially with different applications.

T-1382 Data Requirements

The following data shall be acquired and recorded:

(a) AE event count versus time for each monitoring array.

(b) AE source and/or zone location for all acoustic signals accepted.

(c) AE hit rate for each AE source location cluster.

(d) Relevant AE signal parameter(s) versus time for each data channel.

(e) Location monitored, date, and time period of monitoring.

(f) Identification of personnel performing the analysis.

In addition, the data records shall include any other information required in the applicable procedure (T-1350).

T-1390 REPORTS/RECORDS

T-1391 Reports to Plant System Owner/Operator

T-1391.1 A summary of AE monitoring results shall be prepared monthly. This should be a brief, concise report for management use.

T-1391.2 Reporting requirements in the event of unusual AE indications shall be specified by the plant system owner/operator and identified in the procedure (T-1350).

T-1391.3 A summary report on the correlation of monitoring data with the evaluation criteria shall be provided to the plant system owner/operator.

T-1391.4 Upon completion of each major phase of the monitoring effort, a comprehensive report shall be prepared. This report shall include the following:

(a) complete identification of the plant system/component being monitored including material type(s), method(s) of fabrication, manufacturer's name(s), and certificate number(s)

(b) sketch or manufacturer's drawing with component dimensions and sensor locations

(c) plant system operating conditions including pressurizing fluid, temperature, pressure level, etc.

(d) AE monitoring environment including temperature, radiation and corrosive fumes if appropriate, sensor accessibility, background noise level, and protective barrier penetrations utilized, if any

(e) a sketch or manufacturer's drawing showing the location of any zone in which the AE response exceeded the evaluation criteria

(f) any unusual events or observations during monitoring

(g) monitoring schedule including identification of any AE system downtime during this time period

(h) names and qualifications of the AE equipment operators

(i) complete description of the AE instrumentation including manufacturer's name, model number, sensor types, instrument settings, calibration data, etc.

T-1392 Records

T-1392.1 Administrative Records. The administrative records for each AE monitoring application shall include the applicable test plan(s), procedure(s), operating instructions, evaluation criteria, and other relevant information, as applicable.

T-1392.2 Equipment Qualification and Calibration Data. The pre-installation and post-installation AE system qualification and calibration records including signal attenuation data and AE system performance verification checks shall be retained. Disposition of these records following AE system recalibration shall be specified by the plant system owner/operator.

T-1392.3 Raw and Processed AE Data. The raw data records shall be retained at least until the AE indications have been independently verified. The retention period for the processed data records shall be as specified in the procedure (T-1350).

T-1393 Record Retention Requirements

All AE records shall be maintained as required by the referencing Code section and the procedure (T-1350).

ARTICLE 13
MANDATORY APPENDICES

APPENDIX I — NUCLEAR COMPONENTS

I-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of metallic components in nuclear plant systems. The requirements of Appendix V — Hostile Environment Applications shall also apply to continuous AE monitoring of nuclear plant systems.

I-1320 TERMS SPECIFIC TO THIS APPENDIX

See Appendix VII for definitions of terms specific to this Appendix.

I-1330 EQUIPMENT QUALIFICATION

I-1331 Preamplifiers

The internal electronic noise of the preamplifiers shall not exceed 7 microvolts rms referred to the input with a 50-ohm input termination. The frequency response band of the amplitude shall be matched to the response profile determined for the AE sensors.

I-1332 Monitor System

Acceptable performance, including dynamic range, of the complete AE monitor (without sensors) shall be verified using an electronic waveform generator prior to installation. Sinusoidal burst signals from the waveform generator shall be input to each preamplifier to verify that the signal amplification; data processing functions; data processing rate; and data analysis, display, and storage meet the requirements of this Article. (NOTE: AE signal source location performance is tested under T-1362.1.) The system shall be evaluated using input signals of 0.5 and 10.0 mV peak-to-peak amplitude; 0.5 and 3.0 millisecond duration; and 100 kHz, and 1.0 MHz frequency from the waveform generator.

I-1340 SENSORS

I-1341 Sensor Type

The AE sensors shall be capable of withstanding the ambient service environment (i.e., temperature, moisture, vibration, and nuclear radiation) for a period of two years. Refer to T-1332 and Appendix V, para. V-1320, for additional sensor requirements. In monitoring nuclear components, in addition to high temperature [≈600°F (320°C) in most locations], the environment at the surface of the component may also include gamma and neutron radiation. In view of the neutron radiation, a waveguide high temperature AE sensor such as the type described in Appendix V should be used to isolate the critical elements of the sensor (piezoelectric crystal and associated preamplifier) from the neutron radiation field.

I-1342 Frequency Response

The frequency response band of the sensor/amplifier combination shall be limited to avoid interference from background noise such as is caused by coolant flow. Background noise at the locations to be monitored shall be characterized in terms of intensity versus frequency prior to selection of the AE sensors to be used. This information shall be used to select the appropriate frequency bandwidth for AE monitoring. The sensor response roll off below the selected monitoring frequency shall be at a minimum rate of 15 dB per 100 kHz, and may be achieved by inductive tuning of the sensor/preamplifier combination. The high end of the frequency response band should roll off above 1 MHz at a minimum rate of 15 dB per octave to help reduce amplifier noise. These measurements shall be made using the helium gas jet technique described in T-1342.1 and T-1361.

I-1343 Signal Processing

The threshold for all sensor channels shall be set at 0.5 to 1.0 V_{peak} above the sensor channel background noise level and all channels shall be set the same.

I-1350 CALIBRATION

I-1351 Calibration Block

The calibration block used to qualify AE sensors shall be a steel block with minimum dimensions of 4 × 12 × 12 in. (100 × 300 × 300 mm) with the sensor mounted in the center of a major face using the acoustic coupling technique to be applied during in-service monitoring.

I-1352 Calibration Interval

The installed AE monitor system shall be recalibrated in accordance with T-1360 during each refueling or maintenance outage, but no oftener than once every 24 months.

I-1360 EVALUATION/RESULTS

(a) The monitoring procedure (T-1350) shall specify the acceptance criteria for crack growth rate.

(b) The AE data shall be evaluated based on AE rate derived from signals accepted by the signal identification function and identified with a specific area of the pressure boundary.

(c) The data shall be analyzed to identify an increasing AE rate that is indicative of accelerating crack growth.

(d) The quantitative crack growth rate shall be estimated using the relationship:

$$\frac{da}{dt} = 290\left(\frac{dN}{dt}\right)^{0.53}$$

where

da/dt = crack growth rate in microinches/second
dN/dt = the AE rate [AE as defined in (b) above] in events/second

(e) If the estimated crack growth rate exceeds the acceptance criteria, the flaw area shall be examined with other NDE methods at the earliest opportunity.

APPENDIX II — NON-NUCLEAR METAL COMPONENTS

II-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of non-nuclear metal components. The principal objective is to monitor/detect acoustic emission (AE) sources caused by surface and internal discontinuities in a vessel wall, welds, and fabricated parts and components.

II-1320 EQUIPMENT/QUALIFICATIONS

II-1321 Sensor Response

Acoustic emission sensors shall have a resonant response between 100 kHz to 400 kHz. Minimum sensitivity shall be −85 dB referred to 1 volt/microbar determined by a face-to-face ultrasonic test. Sensors shall have a frequency response with variations not exceeding 4 dB from the peak response. Acoustic emission sensors in a face-to-face ultrasonic test (or equivalent) shall not vary in peak sensitivity by more than 3 dB from when they were new.

II-1322 Couplant

Couplant shall provide consistent coupling efficiency for the duration of the test.

II-1323 Preamplifier

The preamplifier shall be located within 6 ft (1.8 m) from the sensor, and differential preamplifiers shall have 40 dB of common-mode noise rejection. Frequency response shall not vary more than 3 dB over the operating frequency range of the sensors when attached. Filters shall be of the band pass or high pass type and shall provide a minimum of 24 dB of common-mode rejection.

II-1324 Signal Cable

Power signal cable shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB per foot of cable length. Recommended maximum cable length is 500 ft (150 m).

II-1325 Power Supply

A stable, grounded electrical power supply should be used.

II-1326 Main Amplifier

The main amplifier gain shall be within 3 dB over the range of 40°F—125°F (5°C—50°C).

II-1327 Main Processor

The main processor(s) shall have circuits for processing sensor data. The main processor circuits shall be capable of processing hits, counts, peak amplitudes, and MARSE on each channel, and measure the following:

(a) Threshold. The AE instrument shall have a threshold control accurate to within ±1 dB over its useful range.

(b) Counts. The AE counter circuit shall detect counts over a set threshold with an accuracy of ±5%.

(c) Hits. The AE instrument shall be capable of measuring, recording, and displaying a minimum of 20 hits/sec total for all channels.

(d) Peak Amplitude. The AE circuit shall measure peak amplitude with an accuracy of ±2 dB. Useable dynamic range shall be a minimum of 60 dB with 1 dB resolution over the frequency bandwidth used. Not more than 2 dB variation in peak detection accuracy shall be allowed over the stated temperature range. Amplitude values shall be specified in dB and must be referenced to a fixed gain output of the system (sensor or preamplifier).

(e) Energy. The AE circuit shall measure MARSE with an accuracy of ±5%. The useable dynamic range for energy shall be a minimum of 40 dB.

(f) Parametric Voltage. If parametric voltage is measured, it shall be measured to an accuracy of ±2% of full scale.

II-1330 SENSORS

II-1331 Sensor Mounting/Spacing

Sensor location and spacing shall be based on attenuation characterization, with the test fluid in the vessel, and a simulated source of AE. Section V, Article 12, Nonmandatory Appendices should be referenced for vessel sensor placement. Consideration should be given to the possible attenuation effects of welds.

II-1332 Sensor Spacing for Multichannel Source Location

Sensors shall be located such that a lead break at any location within the examination area is detectable by at least the minimum number of sensors required for the multichannel source location algorithm, with the measured amplitude specified by the referencing Code Section. Location accuracy shall be within a miximum of 2 wall thicknesses or 5% of the sensor spacing distance, whichever is greater.

II-1333 Sensor Spacing for Zone Location

When zone location is used, sensors shall be located such that a lead break at any location within the examination area is detectable by at least one sensor with a measured amplitude not less than specified by the referencing Code Section. The maximum sensor spacing shall be no greater than one-half the threshold distance. The threshold distance is defined as the distance from a sensor at which a pencil-lead break on the vessel produces a measured amplitude equal to the evaluation threshold.

II-1340 CALIBRATION

II-1341 Manufacturer's Calibration

Purchased AE system components shall be accompanied by manufacturer's certification of performance specifications and tolerances.

II-1342 Annual Calibration

The instrumentation shall have an annual, comprehensive calibration following the guideline provided by the manufacturer using calibration instrumentation meeting the requirements of a recognized national standard.

II-1343 System Performance Check

Prior to beginning the monitoring period, the AE instrument shall be checked by inserting a simulated AE signal at each main amplifier input. The device generating the simulated signal shall input a sinusoidal burst-type signal of measurable amplitude, duration, and carrier frequency. On-site system calibration shall verify system operation for threshold, counts, MARSE, and peak amplitude. Calibration values shall be within the range of values specified in II-1327.

II-1344 System Performance Check Verification

Verification of sensor coupling and circuit continuity shall be performed following sensor mounting and system hookup and again following the test. The peak amplitude response of each sensor to a repeatable simulated AE source at a specific distance from the sensor should be taken prior to and following the monitoring period. The measured peak amplitude should not vary more than ±4 dB from the average of all the sensors. Any channel failing this check should be repaired or replaced, as necessary. The procedure will indicate the frequency of system performance checks.

II-1350 EVALUATION

II-1351 Evaluation Criteria — Zone Location

All data from all sensors shall be used for evaluating indications. The AE criteria shown in Table II-1351 provide one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria used for each application shall be as specified in the referencing Code Section and the AE procedure (see T-1350).

TABLE II-1351
AN EXAMPLE OF EVALUATION CRITERIA FOR ZONE LOCATION

	Pressure Vessels (Other Than First Hydrostatic Test) Using Zone Location
Emissions during hold	Not more than *E* hits beyond time *T*
Count rate	Less than *N* counts per sensor for a specified load increase
Number of hits	Not more than *E* hits above a specified amplitude
Large amplitude	Not more than *E* hits above a specified amplitude
MARSE or amplitude	MARSE or amplitudes do not increase with increasing load
Activity	Activity does not increase with increasing load
Evaluation threshold, dB	50 dB

TABLE II-1352
AN EXAMPLE OF EVALUATION CRITERIA FOR MULTISOURCE LOCATION

	Pressure Vessels (Other Than First Hydrostatic Test) Using Multisource Location
Emissions during hold	Not more than *E* hits from a cluster beyond time *T*
Count rate	Less than *N* counts from a cluster for a specified load increase
Number of hits	Not more than *E* hits from a cluster above a specified amplitude
Large amplitude	Not more than *E* hits from a cluster above a specified amplitude
MARSE or amplitude	MARSE or amplitudes from a cluster do not increase with increasing load
Activity	Activity from a cluster does not increase with increasing load
Evaluation threshold, dB	50 dB or specified in procedure

II-1352 Evaluation Criteria — Multisource Location

All data from all sensors shall be used for evaluating indications. The AE criteria shown in Table II-1352 provide one basis for assessing the significance of AE indications. These criteria are based on a specific set of AE monitoring conditions. The criteria used for each application shall be as specified in the referencing Code Section and the AE procedure (see T-1350).

APPENDIX III — NON-METALLIC COMPONENTS

III-1310 SCOPE

This Appendix specifies supplemental requirements for continuous monitoring of non-metallic (fiber reinforced plastic) components.

III-1320 BACKGROUND

Non-metallic (FRP) components such as pressure vessels, storage tanks, and piping, are typically used at relatively low temperature. Due to high attenuation and anisotropy of the material, AE methodology has proven to be more effective than other NDE methods.

III-1321 References

(a) Pressure Vessels. Section V, Article 11 — Acoustic Emission Examination of Fiberglass Tanks/Vessels

(b) Atmospheric Tanks. Section V, Article 11 — Acoustic Emission Examination of Fiberglass Vessels, ASNT/CARP Recommended Practice ASTM E 1067: Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin Tanks/Vessels

(c) Piping. ASTM E 1118 — Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

III-1330 MATERIAL CONSIDERATIONS

High attenuation and anisotropy of the material are controlling factors in sensor frequency, source location accuracy, and sensor spacing.

III-1331 Sensor Frequency

Sensors used for monitoring FRP equipment shall be resonant in the 20–200 kHz frequency range.

III-1332 Source Location Accuracy

III-1332.1 Exact solution source location techniques shall be used in monitoring FRP where high accuracy is required. For these applications special precautions will be taken to account for unpredictable acoustic velocity variations in the material. Sensor spacing shall be no greater than 20 in. (500 mm).

III-1332.2 Zone location techniques require the AE signal to hit only one sensor to provide useful location data. Sensor spacing of 5 ft–20 ft (1.5 m–6.0 m) may be used to cover large areas or the entire vessel.

III-1340 CALIBRATION

III-1341

A manufacturer's calibration of the instrumentation should be conducted on an annual basis. Instrumentation used for calibration shall be referenced to NIST.

III-1342

Periodic field calibration shall be performed with an AE waveform generator to verify performance of the signal processor.

III-1343

Hsu-Nielsen lead break and/or gas jet performance verification techniques (T-1362.2) shall be performed periodically to check all components including couplant, sensor, signal processor, and display.

III-1344

Low amplitude threshold (LAT) shall be determined using the 4 ft by 6 ft by $\frac{1}{2}$ in. (1.2 m × 1.8 m × 13 mm) 99% pure lead sheet. The sheet shall be suspended clear of the floor. The LAT threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 4 ft, 3 in. (1.3 m) from the sensor. All lead breaks shall be done at an angle of approximately 30 deg. to the surface with a 0.1 in. (2.5 mm) lead extension. The sensor shall be mounted 6 in. (150 mm) from the 4 ft (1.2 m) side and mid-distance between 6 ft (1.8 m) sides.

III-1345

High amplitude threshold (HAT) shall be determined using a 10 ft by 2 in. by 12 in. (3.0 m × 50 mm × 300 mm) clean, mild steel bar. The bar shall be supported at each end on elastomeric or similar isolating pads. The HAT threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 7 ft (2.1 m) from the sensor. All lead breaks shall be done at an angle of approximately 30 deg. to the surface with a 0.1 in. (2.5 mm) extension. The sensor shall be mounted 12 in. (300 mm) from the end of the bar on the 2 in. (50 mm) wide surface.

III-1350 EVALUATION/RESULTS

III-1351 Evaluation Criteria

The monitoring procedure (T-1350) shall specify the acceptance criteria.

III-1351.1 AE activity above defined levels indicates that damage is occurring.

III-1351.2 Felicity ratio from subsequent loadings to a defined level can indicate the amount of previous damage.

III-1351.3 Emission activity during periods of contact load indicates that damage is occurring at an accelerating rate.

III-1352 Source Mechanism

III-1352.1 Matrix cracking, fiber debonding, and matrix crazing are characterized by numerous low amplitude acoustic emission signals. Matrix cracking and fiber debonding are generally the first indications of failure. Matrix crazing is normally an indication of corrosion or excessive thermal stress.

III-1352.2 Delamination is characterized by high signal strength, medium amplitude AE activity. This type of failure is typically found at joints with secondary bonds.

III-1352.4 High amplitude AE activity (over High Amplitude Threshold) is associated with fiber breakage and is an indication of significant structural damage.

APPENDIX IV — LIMITED ZONE MONITORING

IV-1310 SCOPE

This Appendix specifies supplemental requirements for applications involving limited zone monitoring, where one of the objectives is to consciously limit the area or volume of the component or pressure boundary that is monitored by AE. Typical reasons for limiting the monitored area include: (a) observe the behavior of a known flaw at a specific location; (b) restrict the AE response to signals emanating from specific areas or volumes of the pressure boundary (e.g., restrict the area monitored by AE to one or more nozzle-to-vessel welds, monitor specific structural welds, etc.); (c) restrict the AE examination to areas of known susceptibility to failure due to fatigue, corrosion, etc.; or (d) improve the signal-to-noise ratio.

IV-1320 TERMS SPECIFIC TO THIS APPENDIX

See Appendix VII for definitions of terms specific to this Appendix.

IV-1330 GENERAL

IV-1331 Techniques

Limited zone monitoring is accomplished by installing sensors in or around the area of interest. Signals originating from outside the area of interest are excluded from the analysis using techniques such as triangulation, amplitude discrimination, coincidence detection, or signal arrival sequence.

IV-1332 Guard Sensor Technique

One common signal arrival sequence technique uses guard sensors to limit the area of interest. The guard sensor technique involves placing additional sensors further outside the area of interest than the detection sensors. Signals arriving at a guard sensor before any of the detection sensors are rejected. Signals originating from within the area of interest arrive at a detection sensor before any of the guard sensors and are accepted by the data acquisition and analysis process.

IV-1333 Other Techniques

The preceding descriptions of typical limited zone monitoring techniques shall not preclude the use of other techniques to provide this function.

IV-1340 REQUIREMENTS

IV-1341 Procedure

When limited zone monitoring is intended, the technique used to accomplish this function shall be described in the procedure (T-1350). Any technique, or combination of techniques, may be utilized to accomplish limited zone monitoring provided the technique(s) is described in the applicable procedure.

IV-1342 Redundant Sensors

Where appropriate, redundant sensors should be used to provide additional assurance that the failure of a single sensor will not preclude continued operation of the AE system throughout the specified monitoring period.

IV-1343 System Calibration

During the system calibration performed in accordance with T-1362, the effectiveness of the limited zone monitoring technique(s) shall be demonstrated by introducing artificial AE signals both inside and outside the area of interest. The AE system shall accept at least 90% of the signals that originate inside the area of interest, and reject at least 90% of the signals that originate outside the area of interest. Such signal discrimination may be accomplished using any of the techniques listed above as specified in the procedure (T-1350).

IV-1350 EVALUATION/RESULTS

Data processing and interpretation shall be performed consistent with the objectives of limited zone monitoring. Precautions shall be taken to confirm that signals originating from inside the area of interest are not confused with signals originating from outside the area of interest. Care shall also be taken to check that the system's ability to monitor the area of interest was not compromised by excessive noise from outside the area of interest.

IV-1360 REPORTS/RECORDS

All reports of data acquired using the limited zone monitoring approach shall clearly and accurately identify the effective area of interest.

APPENDIX V — HOSTILE ENVIRONMENT APPLICATIONS

V-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of pressure containing components during operation at high temperatures and in other hostile environments. As used herein, high temperature means as any application where the surface to be monitored will exceed 300°F (150°C), which is the nominal upper temperature limit for most general purpose AE sensors. Other hostile environments include corrosive environments, high vapor atmospheres, nuclear radiation, etc.

V-1320 SENSORS

For high temperature applications, special high temperature sensors shall be used. There are two basic types of sensors for such applications. Surface mounted sensors constructed to withstand high temperatures and waveguide sensors which remove the sensor's piezoelectric sensor from the high temperature environment through the use of a connecting waveguide. A thin, soft metal, interface layer between the sensor and the component surface has proven effective for reducing the interface pressure required to achieve adequate acoustic coupling.

V-1321 Surface Mounted Sensors

Sensors to be mounted directly on the surface shall be evaluated for their capability to withstand the environment for the duration of the planned monitoring period. Some sensors rated for high temperature service are limited in the time for which they can survive continuous exposure at their rated temperature.

V-1322 Waveguide Sensors

The waveguide sensors described below are suitable for hostile environment applications where the sensor unit (piezoelectric crystal and 20 dB preamplifier) can be placed in a less hostile environment [e.g., lower temperature of about 200°F (95°C)] through the use of a waveguide no more than 20 ft (6 m) long. The length of the waveguide is not an absolute; however, as the waveguide length increases, the signal attenuation in the waveguide also increases.

Waveguide sensors are a special type of sensor used for hostile environments. A type of waveguide sensor that has been used effectively to monitor components with surface temperatures to 1800°F (980°C) is shown in Fig. V-1322. A waveguide 20 ft (6 m) long was used to move the sensor unit (piezoelectric crystal and 20 dB preamplifier) away from the high temperature to an environment of about 200°F (93°C). The sensor was still exposed to a nuclear radiation environment of about 45,000 Rad/hr gross gamma. When monitoring was completed after 120 days, the sensors were still operating with no evidence of deterioration. These sensor types have been used in various applications with waveguide lengths ranging from 2 to 20 ft (0.6 m to 6 m) for periods up to $2\frac{1}{2}$ years, and the attenuation in a $\frac{1}{8}$ in. (3 mm) diameter Type 308 stainless steel waveguide has been measured to be 0.45 dB/ft (1.5 dB/m).

V-1323 Sensor Monitoring

Refer to T-1332.3 for a discussion of sensor mounting. Most extreme temperature applications require mechanical mounting with pressure coupling of the sensors due to the temperature limitations of glues or epoxies. A sensor mounting fixture held in place by stainless steel bands or magnets has proven to be effective; however, if magnets are used, the ability of the magnet to retain its magnetic properties in the temperature environment must be evaluated. The fixture shown in Fig. V-1323 has been successfully used in a variety of waveguide sensor applications.

This fixture design provides a constant load on the waveguide tip against the component surface through the use of a spring. It has been found through practice that an interface pressure of about 16,000 psi (110 MPa) is required for good acoustic coupling. For the waveguide sensor shown in Fig. V-1322 with a waveguide tip diameter of 0.05 in. (1.25 mm), 30 lb-f (0.13 kN) for the mounting fixture provides the required interface pressure.

V-1324 Signal Cables

Special coaxial cables rated for the expected temperature shall be used to conduct AE signal information from the AE sensor to a location outside of the environment. Refer also to T-1333 and T-1348.

APPENDIX VI — LEAK DETECTION APPLICATIONS

VI-1310 SCOPE

This Appendix specifies supplemental requirements for continuous AE monitoring of metallic and non-metallic components to detect leaks from the pressure boundary. The objective in examining the pressure boundary of systems and components is to assess the leak integrity and identify the leakage area. The requirements of Appendix I — Nuclear Components and Appendix V — Hostile Environment Applications may also be applicable. SE-1211 should be consulted as a general reference.

VI-1320 GENERAL

The desire to enhance leak detection capabilities has led to research to improve acoustic leak detection technology including technology that is applicable to the pressure boundary of nuclear reactors. Several methods are available for detecting leaks in pressure boundary components including monitoring acoustic noise due to fluid flow at a leakage site. The advantages of acoustic monitoring are rapid response to the presence of a leak and the capability to acquire quantitative information about a leak. Acoustic leak detection methods may be used to detect gas, steam, water, and chemical leaks for both nuclear and non-nuclear applications.

VI-1330 EQUIPMENT

VI-1331 Sensor Type

AE sensors with known sensitivity in the frequency range 200 kHz to 500 kHz shall be used in the presence of high background noise. For components in the presence of low background noise, monitoring shall be carried out at lower frequencies. Leak detection at frequencies below

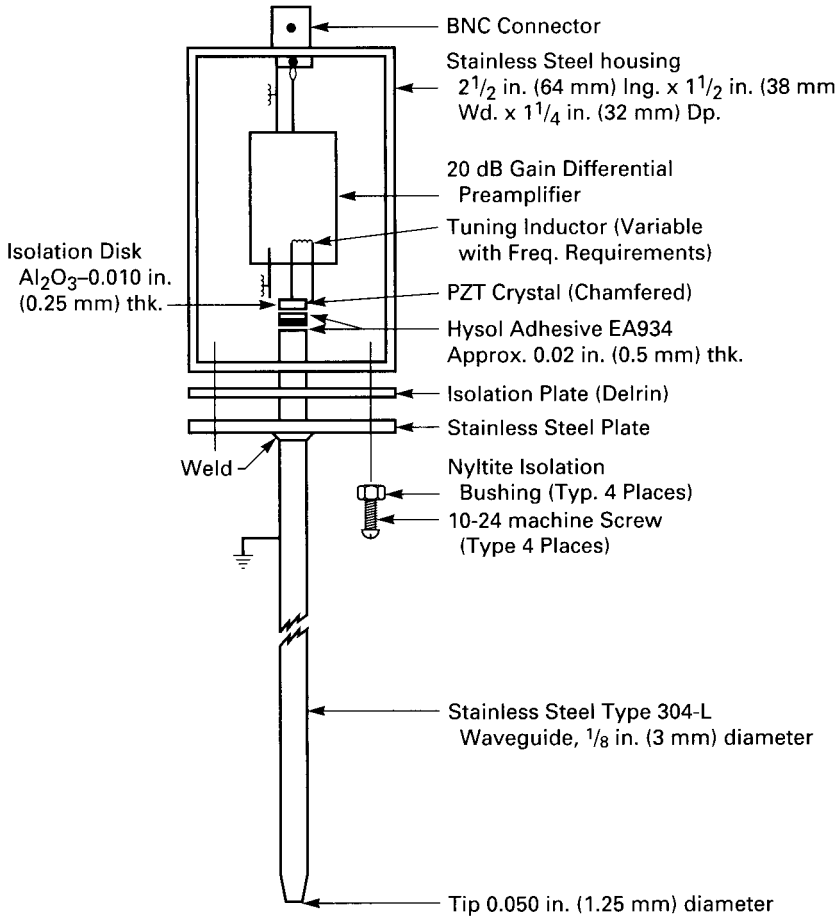


FIG. V-1322 METAL WAVEGUIDE AE SENSOR CONSTRUCTION

100 kHz and as low as 1 kHz may be necessary for leak detection with non-metallic components.

VI-1331.1 Sensor selection shall be based on consideration of the following:

(a) center frequency

(b) bandwidth

(c) ruggedness

(d) response to temperature

(e) humidity

(f) ability of cables and preamplifiers to withstand the specific environment.

Using a simulation, sensor response characteristics and curves of leak rate vs. acoustic signal intensity shall be determined before installation to maximize the utility of the information in the acoustic signal.

VI-1331.2 Sensors not specified in this Appendix may be used if they have been shown to be appropriate for the application and meet the requirements of this Article. Alternate sensors, such as accelerometers, microphones, and hydrophones shall be included.

VI-1332 Waveguide

Waveguides may be used to isolate the sensor from hostile environments such as high temperatures or nuclear radiation for nuclear reactor applications.

VI-1332.1 Waveguide installations shall consider the following waveguide parameters:

(a) length

(b) diameter

(c) surface finish

(d) material of construction (i.e., ferritic steel, stainless steel, aluminum, and ceramic materials)

Waveguides having 1/8 in. to 1/2 in. (3 mm to 13 mm) in diameter and up to 10 in. (250 mm) in length have been shown to be effective and shall be used.

VI-1332.2 Coupling. Appendix V, para. V-1323 describes one method for mounting the waveguide. Others that have been shown effective are:

(a) weld the waveguide to the pressure boundary

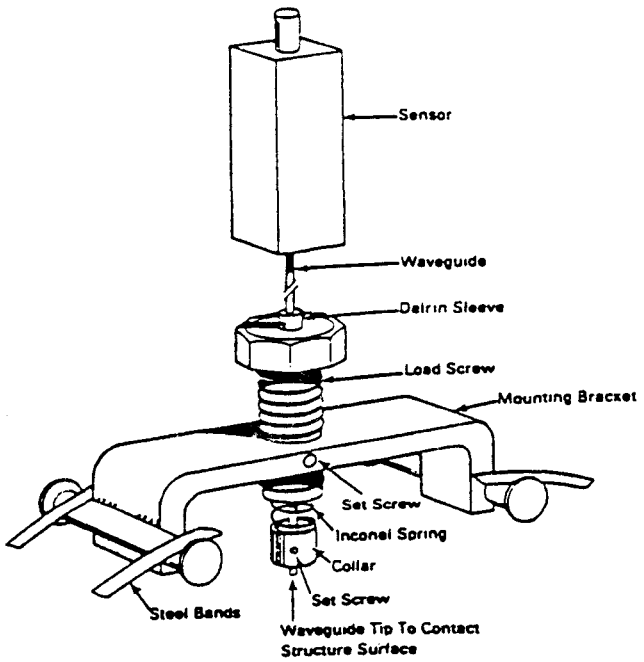


FIG. V-1323 MOUNTING FIXTURE FOR STEEL WAVEGUIDE AE SENSOR

(b) screw the waveguide into a plate attached to the order to mechanically press the waveguide against the metal component

(c) screw the waveguide directly into the pressure boundary component

(d) attach the sensor directly to the component.

Either gold foil or rounded waveguide tips have been shown to be effective when mechanically coupling the waveguide to the pressure boundary component. Occassionally, sensors are mounted and passed through the pressure boundary of a component in order to have the sensor in the process fluid. The sensor(s) shall then be capable of withstanding the ambient service environment of the process fluid. In addition, a safety analysis for installation and monitoring of the system shall be performed.

VI-1333 Electronic Filters

The response of the electronic filter(s) shall be adjustable to achieve the selected monitoring frequency range of operation as needed (see Appendix I). Frequency bandwidths in the range of 200–250 kHz should be available for high background noise environments and 1–200 kHz for low background noise environments.

VI-1340 CALIBRATION

VI-1341 Procedure

A calibration procedure shall be established and shall incorporate either the pencil-lead break and/or gas jet techniques decribed in T-1360 and Appendix I.

VI-1342 Calibration Checks

Sensor calibration checks may be conducted by electronically pulsing one of the sensors while detecting the associated acoustic wave with the other sensors.

VI-1350 EXAMINATION

VI-1351 Implementation of System Requirements

In order to implement an acoustic leak detection and location system, the following preliminary steps shall be accomplished.

(a) identify the acoustic receiver sites

(b) determine the spacing between waveguides or sensors

(c) meet the sensitivity needs for the system requirements

(d) establish the level of background noise

(e) estimate signal-to-noise ratios as a function of distance and level of background noise for acoustic signals in the frequency range selected.

VI-1352 Calibration Procedure

A calibration procedure shall be established. During the monitoring period, a self-checking system shall be performed to assure the system is functioning properly.

VI-1353 Equipment Qualification and Calibration Data

The acoustic equipment qualification and calibration data requirements shall be in accordance with T-1392.

VI-1360 EVALUATION/RESULTS

VI-1361 Leak Indications

Detection of a leak or leakage indication near or at a sensor site will be indicated by an increase in the RMS signal over background noise. The signal increase shall be at least 3 dB or greater above background for a period of at least 30 min.

VI-1362 Leak Location

The general location of a leak can be established by the analysis of the relative amplitude of the RMS signals received by the sensor(s). Leak location may also be determined by cross-correlation analysis of signals received at sensors, to either side of the leak site. When leakage location accuracy is desired, it may be necessary to spatially average the correlograms of the acoustic signals at each sensor site by installing an array of sensors. A minimum of three waveguides, separated by a minimum of 10 cm [4 in. (100 mm)], is required for averaging of correlograms. This allows nine correlograms to be generated and averaged for each pair of sensor locations. Self-checking and calibration for the system shall be in accordance with VI-1340. If acoustic background levels are relatively constant, they may also be used to determine whether a probe is failing.

APPENDIX VII — GLOSSARY OF TERMS FOR ACOUSTIC EMISSION EXAMINATION

VII-1310 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definitions of terms that appear in Article 13, Continuous Acoustic Emission Monitoring.

VII-1320 GENERAL REQUIREMENTS

(a) The Standard Terminology for Nondestructive Examinations (ASTM E 1316) has been adopted by the Committee as SE-1316.

(b) SE-1316 provides the definitions of terms listed in VII-1330(a).

(c) For general terms, such as *Interpretation, Flaw, Discontinuity, Evaluation,* etc., refer to Article 1, Mandatory Appendix I.

(d) Paragraph VII-1330(b) provides a list of terms and definitions that are in addition to SE-1316 and are Code specific.

VII-1330 REQUIREMENTS

(a) All of the terms listed in SE-1316 are used in conjunction with this Article.

(b) The following Code terms are used in conjunction with this Article:

AE Monitor — all of the electronic instrumentation and equipment (except sensors and cables) used to detect, analyze, display, and record AE signals

Continuous Monitoring — the process of monitoring a pressure boundary continuously to detect acoustic emission during plant startup, operation, and shutdown

dB_{AE} — the peak voltage amplitude of the acoustic emission signal waveform expressed by the equation $dB_{AE} = 20 \log V/V_{Ref}$, where V_{Ref} is 1 μV out of the AE sensor crystal

Limited Zone Monitoring — the process of monitoring only a specifically defined portion of the pressure boundary by using either the sensor array configuration, controllable instrumentation parameters, or both to limit the area being monitored

Penetrations — In nuclear applications, the term penetrations refers to step-plugs containing electronic instrumentation cable sections installed through shielding or containment walls to permit passing instrumentation power and information signals through these protective walls without compromising the protective integrity of the wall

Plant/Plant System — the complete pressure boundary system including appurtenances, accessories, and controls that constitute an operational entity

Plant Operation — normal operation including plant warmup, startup, shutdown, and any pressure or other stimuli induced to test the pressure boundary for purposes other than the stimulation of AE sources

Sensor Array — mulitple AE sensors arranged in a geometrical configuration that is designed to provide AE source detection/location for a given plant component or pressure boundary area to be monitored

ARTICLE 14
EXAMINATION SYSTEM QUALIFICATION

T-1410 SCOPE

The provisions of this Article for qualifying nondestructive examination (NDE) systems are mandatory when specifically invoked by the referencing Code Section. The Manufacturer, examination organization, owner, or other user of this Article is responsible for qualifying the examination technique, equipment, and written procedure in conformance with this Article. The referencing Code Section shall be consulted for the following specific detailed requirements:

(a) personnel certification requirements or prerequisites for qualification under the requirements of this Article

(b) examination planning, including the extent of examination

(c) acceptance criteria for evaluating flaws identified during examination

(d) level of rigor required for qualification

(e) examination sensitivity, such as probability of detection and sizing accuracy

(f) records, and record retention requirements

T-1420 GENERAL REQUIREMENTS

T-1421 The Qualification Process

The qualification process, as set forth in this Article, involves the evaluation of general, technical, and performance-based evidence presented within the documented technical justification, and when required, a blind or non-blind performance demonstration.

T-1422 Technical Justification

The technical justification is a written report providing a detailed explanation of the written examination procedure, the underlying theory of the examination method, and any laboratory experiments or field examinations that support the capabilities of the examination method.

The technical justification provides the technical basis and rationale for the qualification, including:

(a) mathematical modeling

(b) field experience

(c) test hierarchy ranking

(d) anticipated degradation mechanism

(e) NDE response by morphology and/or product form

T-1423 Performance Demonstration

The performance demonstration establishes the ability of a specific examination system to achieve a satisfactory probability of detection (POD), by application of the examination system on flawed test specimens. The demonstration test results are used to plot the POD curve and determine the false call probability (FCP) for establishing confidence limitations.

(a) The test specimens shall replicate the object to be examined to the greatest extent practical. Simplified test specimens representative of an actual field situation may be used. The use of specimens with known, identified flaws is preferred, and may be essential for the most rigorous qualification process. A hierarchy of test specimen flaws may be used to minimize qualifications when technically justified (i.e., demonstrations on more challenging degradation mechanisms may satisfy qualification requirements for less challenging mechanisms).

(b) When they sufficiently replicate the object to be tested, performance demonstrations of a limited scope may be used to minimize the costs involved, and facilitate specimen availability. The technical justification must support any limitations to the scope of performance demonstrations.

(c) Personnel qualification shall be based upon blind testing, except where specifically exempted by the referencing Code Section.

(d) The level of rigor applied to the performance demonstration may vary from a simple demonstration on a few flaws, to an extensive test using hundreds of flaws. The level of rigor may also vary between qualifications for the written procedure and examination personnel. More rigorous procedure qualifications can be beneficial for the following reasons:

(1) improved pass-fail rates for personnel;

(2) reduced scope for blind personnel qualification testing;

(3) better understanding of the correlation between the procedure and the damage mechanisms of interest;

(4) more reliable written procedures.

T-1424 Levels of Rigor

Qualification is performed at one of three levels of rigor. The referencing Code Section shall invoke the required level of rigor, to verify the examination system capability to detect and size typical flaws for the damage mechanisms of interest, depending upon their locations and characteristics. When not otherwise specified, the level of rigor shall be set by agreement between the interested parties. The three levels of rigor are:

(a) Low Rigor (Technical Justification only): The requirement for this level of rigor is a satisfactory technical justification report. No performance demonstrations are required for qualification of the examination system.

(b) Intermediate Rigor, (Limited Performance Demonstration): The requirements for this level of rigor are a satisfactory technical justification report, and the successful performance of a demonstration test (blind or non-blind) on a limited number of test specimens. The referencing Code Section shall establish the scope of demonstration requirements, and sets acceptable POD and FCP scores for qualification. When not otherwise specified, the qualification criteria shall be set by agreement between the interested parties.

(c) High Rigor, (Full Performance Demonstration): The requirements for this level of rigor are a satisfactory technical justification report, and the successful performance of blind demonstration tests. The referencing Code Section shall establish the scope of demonstration requirements, and sets acceptable POD and FCP scores for qualification. When not otherwise specified, the qualification criteria shall be set by agreement between the interested parties. A sufficient number of test specimens shall be evaluated to effectively estimate sizing error distributions, and determine an accurate POD for specific degradation mechanisms or flaw types and sizes. A high rigor performance demonstration is generally required to support a Probabilistic Risk Assessment.

T-1425 Planning a Qualification Demonstration

The recommended steps for planning and completing the qualification demonstration, as applicable, are:

(a) Assemble all necessary input information concerning the component, defect types, damage mechanism of interest, and objectives for the examination and qualification of the examination system.

(b) Review the written procedure to verify its suitability for the intended application.

(c) Develop the technical justification for the examination method to be used.

(d) Determine the required level of rigor for the performance demonstration.

(e) Develop performance demonstration criteria using the applicable references.

(f) Conduct the performance demonstration.

(g) Conduct the personnel qualifications.

(h) Compile, document, and evaluate the results.

(i) Determine qualification status, based upon a final evaluation.

T-1430 EQUIPMENT

The equipment used for the performance demonstration of an examination system shall be as specified in the written procedure and the technical justification. After qualification of the examination system, the use of different examination equipment may require requalification (see T-1443).

T-1440 APPLICATION REQUIREMENTS

T-1441 Technical Justification Report

Prior to qualification of any examination system, regardless of the level of rigor, a technical justification report shall be prepared and receive approval by a Level III certified for the specific method to be applied. The technical justification report shall be reviewed and accepted by the owner of the object of interest and, where applicable, to the Jurisdiction, Authorized Inspection Agency (AIA), independent third party, examination vendor, or other involved party. Acceptance of this report by the involved parties is the minimum requirement for qualification of an examination system at the lowest level of rigor. The technical justification report shall address the following minimum topics:

T-1441.1 Description of Component/Flaws to be Examined. The component design, range of sizes, fabrication flaw history, and any anticipated damage mechanisms (for in-service evaluations) for the object of interest shall be analyzed to determine the scope of the examinations, the types and sizes of critical flaws to be detected, and the probable location of flaws. The scope of the written procedure shall define the limits for application of the procedure (e.g., materials, thickness, diameter, product form, accessibility, examination limitations, etc.).

(a) The flaws of interest to be detected; their expected locations, threshold detection size, critical flaw size, orientation, and shape shall be determined, serving as a

guideline for development of the written procedure. Critical flaw sizes (calculated from fracture mechanics analysis) and crack growth rates are important considerations for determining flaw recording and evaluation criteria. The minimum recordable flaw size must be smaller than the critical flaw size, and include consideration of the estimated or observed crack growth rates and the observed quality of workmanship during fabrication. Flaw evaluation must be based upon precluding the formation of critically sized flaws prior to the next inspection, or for the estimated remaining life of the object during normal operations.

(b) Object or technique geometry, environmental conditions, examination limitations, and metallurgical conditions may limit the accessibility for evaluating the object. Examination procedure or equipment modifications may be required to gain access to the area of interest to be examined.

(c) The acceptance criteria for the demonstration shall be provided.

(d) Additional issues to consider for inclusion in the technical justification may include:

(1) historical effectiveness of procedure;

(2) documentation for prior demonstrations;

(3) extent of prior round robin tests;

(4) observed flaw detection rates, probability of detection, and false call rates;

(5) acceptable rejection/acceptance rates; and

(6) sizing accuracy.

T-1441.2 Overview of Examination System. A general description of the examination system, with sufficient detail to distinguish it from other systems, shall be included within the technical justification report. The description shall include, as applicable, sizing techniques, recording thresholds, and techniques to be used for interpreting indications. If a combination of equipment is used, the applicable conditions for specific equipment combinations shall be adequately described.

T-1441.3 Description of Influential Parameters. The influence of inspection parameters on the examination system shall be considered, including equipment selection, sensitivities, instrument settings, data analysis, and personnel qualifications. The justification for parameter selections shall be based upon the flaws of interest, and include an explanation of why the selected parameters will be effective for the particular examination and expected flaws.

(a) Procedure requirements, including essential variables to be addressed, may be found in the Mandatory Appendix associated with the examination method, or in the referencing Code Section.

(b) Personnel certification requirements, in addition to method specific Level II or III certification, may be advisable under some conditions. When using established techniques for a low rigor application (e.g., for examination of more readily detected damage mechanisms, or where less critical components are involved) a method specific Level II or III certification is adequate. When an intermediate or high rigor application is required, additional personnel requirements shall be considered and, if required, so specified. This may include quantitative risk based criteria for the selection of components to be examined, or completion of a blind performance demonstration. For examination techniques performed by a team of examiners, the specific qualification requirements for each team member shall be addressed.

T-1441.4 Description of Examination Techniques. A justification for the effectiveness of the selected examination technique used in the written procedure for detecting flaws of interest shall be included. The sensitivity settings for recording flaws, flaw orientation, critical flaw size, anticipated degradation mechanism (for in-service applications), and the influence of metallurgical and geometric affects shall be addressed in the justification. A description of the method for distinguishing between relevant and non-relevant indications, justification for sensitivity settings, and the criteria for characterizing and sizing flaws shall be included.

T-1441.5 Optional Topics for Technical Justification. The following topics may be addressed within the technical justification to improve the understanding of the techniques to be applied.

(a) Description of Examination Modeling. A description of the examination modeling used to develop the procedure, plot indications, predict flaw responses, design mockups, show coverage, and qualify written procedures may be included. Models are required to be validated before use. The referencing Code Section shall establish the criteria for validating models. When not otherwise specified, the modeling validation criteria shall be set by agreement between the interested parties. Models can be used with qualified written procedures to demonstrate the anticipated effectiveness of procedure revisions when parameters such as geometry, angle, size, and access limitations are changed. The written procedure may be qualified or requalified using a minimum number of mockups with adequate justification.

(b) Description of Procedure Experience. Prior experience with a written procedure may be included in the technical justification, and used to support revisions to the procedure. Documentation of similar demonstrations relevant to the proposed examination may be included. Experimental evidence to show the effect of applicable

variables may also be cited and considered when developing the written procedure.

T-1442 Performance Demonstration

Examination systems requiring qualification at intermediate or high levels of rigor shall also pass a performance demonstration. The specimen test set and pass/fail criteria to be used in the performance demonstration shall be determined by the owner of the object; and, where applicable, shall be acceptable to the Jurisdiction, Authorized Inspection Agency, independent third party, examination vendor, inspection agency, or other involved party.

(a) The procedure shall be demonstrated by performing an examination of an object or mockup. The examiner conducting the demonstration shall not have been involved in developing the procedure. The completed report forms provide documentation of the demonstration. Qualification of the procedure is only valid when applying the same essential variables recorded during the demonstration. Changes to essential variables require requalification of the procedure. Editorial changes to the procedure, or changes to nonessential variables, do not require requalification of the procedure.

(b) The demonstration of the written procedure may use blind or non-blind certified personnel. Blind performance demonstrations qualify the complete examination system (i.e., the equipment, the written procedure, and the examiner). Non-blind demonstrations only qualify the procedure and the equipment. All recordable indications shall be sized and located. The detection records shall note whether indications are located correctly. Depth, height, and length sizing capabilities are only qualified by a blind performance demonstration.

(c) Demonstrations can be performed by a non-blind demonstration using a few flaws, a demonstration mandated by the referencing Code Section, reiterative blind testing, a combination of multiple small specimen demonstrations; or using a rigorous, statistically based demonstration based on binomial distributions with reduced, one-sided confidence limits. Acceptable demonstration methodologies shall be described in the technical justification for that procedure.

(d) An individual or organization shall be designated as the administrator of the demonstration process. The roles of the administrator include:

(1) reviewing the technical justification;

(2) reviewing the procedure and its scope of applicability;

(3) ensuring that all essential variables are included in the procedure and demonstration;

(4) assembling the test specimens;

(5) grading the demonstrations;

(6) developing the protocol;

(7) maintaining security of the samples; and

(8) maintaining the demonstration records.

For straightforward applications, the administrator may be a department within the owner's organization. For complex demonstrations, or when Code or user requirements dictate, it may be appropriate to use a disinterested third party.

T-1443 Examination System Re-qualification

The original qualification applies only to the system and essential variables described in the technical justification report and the written procedure. If essential variables are changed, requalification is required. Requalification may be accomplished by one of the following means:

(a) The characteristics of the new equipment can be compared to the qualified equipment. If they are essentially identical, the new equipment can be substituted, except when the referencing construction Code invokes more stringent requirements for substituting equipment.

(b) New equipment may be requalified by conducting another complete examination qualification. A hierarchical approach should be used to qualify the new equipment by conducting the demonstration on the most difficult test specimens. Then there is no need to requalify the equipment on the entire set of test specimens.

(c) Modeling may be used to requalify a procedure when proper justification supports such an approach.

T-1450 CONDUCT OF QUALIFICATION DEMONSTRATION

T-1451 Protocol Document

A protocol document shall be prepared to ensure continuity and uniformity from qualification-to-qualification. The protocol document forms the basis for third party oversight, and sets the essential variables to be qualified, ensuring portability of the qualification. The protocol document commonly takes the form of a written procedure and associated checklist, documenting the process followed during qualification. This document is developed collectively with the involvement of all the affected parties (i.e., the owner, and, when applicable, the Jurisdiction, AIA, independent third party, examination vendor, or other involved party).

A key element of the protocol document is the Pass/Fail criteria. An alternative evaluation criteria that may be applied is an "achieved level of performance criteria." For this criteria, an examiner demonstrates the technique, including sizing capabilities, and the qualification is based

on the detection range the examiner achieves during the demonstration. Examiners qualified under these criteria are permitted to conduct examinations within their qualified capabilities.

T-1452 Individual Qualification

The performance demonstration requirements found in T-1440 qualify the examination system (i.e. equipment, written procedure, and personnel) as a unit. As an alternative, a two-stage qualification process may also be applied. The first stage of this process involves a performance demonstration to qualify the system procedure/equipment. The procedure/equipment qualification requires several qualified examiners to evaluate the specimen set, with the results meeting predetermined requirements more stringent than personnel pass/fail requirements. After the procedure/equipment has been qualified, individual examiners using the qualified procedure/equipment combination need only to perform a limited performance demonstration.

The principal incentive for adopting this form of test is to reduce costs in personnel qualification of a widely used procedure. The procedure/equipment may be qualified/developed in a non-blind fashion but the personnel shall take blind tests. This two-step process also precludes the possibility of an examiner attempting to pass a demonstration test with inadequate procedures or equipment.

T-1460 CALIBRATION

Calibration of equipment shall be in accordance with the written procedure used to conduct the performance demonstration.

T-1470 EXAMINATION

The performance demonstration shall be conducted in accordance with the written procedure, using the techniques and equipment described in the technical justification. Supplemental information for conducting various modes of performance demonstrations is provided in the following paragraphs.

T-1471 Intermediate Rigor Detection Test

The objective of an intermediate rigor performance demonstration test is to reveal inadequate procedures and examiners. Following are typical options for flaws in specimen test sets used for intermediate rigor performance demonstrations:

(a) Specimens should accurately represent the component to be examined to the greatest extent possible, with at least 10 flaws or grading units as a minimum. A POD of 80% with a false call rate less than 20% is required for acceptable performance.

(b) Less than 10 flaws or grading units are used, but they shall be used in a blind fashion. The flaws are reused in an iterative, blind, and random process. This is an economic way to increase the sample set size. Eighty percent of the flaws are required to be detected. The false call rate should be less than 20%.

(c) Between 5 and 15 flaws or grading units are used with at least the same number of unflawed grading units. A POD of 80% with a false call rate less than 20% is required for acceptable performance.

(d) Sample set size shall be sufficient to ensure that most examiners with an unacceptable POD will have difficulty passing the demonstration, while most examiners with an acceptable POD will be able to pass the demonstration.

T-1472 High Rigor Detection Tests

The following guidelines describe the methodology for constructing POD performance demonstration tests for examination system qualification. In order to construct any of the detection tests mentioned in this appendix, the following information must be assembled:

(a) The type of material and flaws the procedure is supposed to detect.

(b) The size of the critical flaw for this application.

(c) The minimum acceptable POD that inspection should achieve for critical flaws. (Call this POD_{min}.)

(d) The maximum acceptable false call probability that the inspection should display. (Call this FCP_{max}.)

(e) The level of confidence that the test is supposed to provide. (The most widely applied level of confidence being 95%.)

T-1472.1 Standard Binomial Detection Test. The examiner is subjected to a blind demonstration. The flawed grading units contain critical flaws (i.e., flaws near the critical flaw size) so that a POD calculated from this data estimates the POD for critical flaws. After the examination, the POD and FCP scores are calculated by comparing the number of detections classified as flaws to the number of flawed or blank grading units examined. In other words:

$$\text{POD Score} = \frac{\text{\# of flawed grading units as flaws}}{\text{Total \# of flawed grading units examined}} \quad (1)$$

$$\text{FCP Score} = \frac{\text{\# of blank grading units classified as flaws}}{\text{Total \# of blank grading units examined}} \quad (2)$$

The POD and FCP are supported by tolerance bands called "α bounds" to describe the statistical uncertainty

in the test. (In the case of POD a lower α bound is used, while for FCP, an upper α bound is used.) The examiner's score is acceptable if the lower bound on POD score is above POD_{min} , and the upper bound on FCP score is below FCP_{max}.

The α bounds are calculated using standard binomial formulas, shown below.

Where:

D = Number of detections recorded
N = Number of grading units that contain flaws (for POD calculations) or that are blank (for FCP calculations)
P_{upper} = upper α bound
P_{lower} = lower α bound

$$\alpha = \beta(P_{lower};\ D,\ N - D + 1) \quad (3)$$

$$\alpha = 1 - \beta(P_{upper};\ D + 1,\ N - D) \quad (4)$$

where $\beta(z;\ c_1,c_2)$ is a beta distribution with parameters c_1 and c_2. The design of a statistically significant sample set for this test is based on the above binomial formulas.

A POD of 95% with a 90% confidence implies that there is a 90% probability that 95% is an underestimate of the true detection probability. In other words, the confidence level, α describes how reliable the qualification test must be. If 10 flaws are in the test, then on the basis of 2 misses, there is a 90% confidence that the true inspection reliability is greater than 55%. If 95% confidence is desired, then the true inspection reliability is greater than 33.8%. If all 10 flaws were detected, then the POD would be 79%. To obtain a 90% POD at a 95% confidence level requires a minimum of 29 flaws out of 29 flaws to be detected.

Table T-1472.1 shows the relationship between smallest number of flaws, confidence level, probability of detection, and misses by calculating the formula above for various scenarios. It can be used to develop the size of the test set. The user is free to select the actual number of flawed and blank locations (i.e., the sample size) employed in the test. The user's choice for sample size will be governed by two competing costs, (1) the cost of constructing test specimens, and (2) the cost of failing a "good" examiner. If the user chooses to perform a large test, the confidence bounds associated with the POD scores will be small, so a "good" examiner will have an excellent chance for passing the test. However, if an abbreviated test is given, the confidence bounds will be large, and even a good examiner will frequently fail a test.

In fact, with a binomial test such as this, there is a smallest sample size that can be used. If a sample size smaller than the smallest sample size is used, it is impossible to ever pass the test, because the confidence bounds are so wide. With the smallest sample size, the examiner has to obtain a perfect score (i.e., $POD = 1$, or $FCP = 0$) to pass. The smallest sample size depends upon the detection threshold and the confidence level chosen for the test. For example, as the minimum acceptable POD is set closer to unity, the minimum sample size becomes larger. Table T-1472.1 presents the minimal sample size for various confidence levels, and POD/FCP thresholds.

As one can see from this table, quite a large sample set is required if high detection thresholds are required for the inspection. If exceptionally high detection thresholds are required, the standard binomial test described in this appendix may not be the most efficient testing strategy.

As a general rule, the test should include as many blank as flawed location, but this proportion may be altered depending upon which threshold (POD or FCP) is more stringent.

As developed in this section, the standard binomial test examines POD for one flaw size only, the critical flaw size. It is possible to include more flaw sizes in the

TABLE T-1472.1
TOTAL NUMBER OF SAMPLES FOR A GIVEN NUMBER OF MISSES AT A SPECIFIED CONFIDENCE LEVEL AND POD

Level of Confidence	Number of Misses	Probability of Detection		
		90%	95%	99%
90%	0	22	45	230
	1	38	77	388
	2	52	105	531
	3	65	132	667
	4	78	158	798
	5	91	184	926
	10	152	306	1,000+
	20	267	538	1,000+
95%	0	29	59	299
	1	46	93	473
	2	61	124	628
	3	76	153	773
	4	89	181	913
	5	103	208	1,000+
	10	167	336	1,000+
	20	286	577	1,000+
99%	0	44	89	458
	1	64	130	662
	2	81	165	838
	3	97	198	1,000+
	4	113	229	1,000+
	5	127	259	1,000+
	10	197	398	1,000+
	20	325	656	1,000+

test. Each included flaw size would contain the minimum number of flaws required by Table T-1472.1. For example, a 90% detection rate at a 90% confidence level for four different flaw size intervals would require 22 flaws in each size interval if no misses are allowed for a total of 88 flaws.

T-1472.2 Two-Stage Detection Test. The basic component of the two-stage demonstration test is the Standard Binomial Detection Test described in T-1472.1. The two-stage test applies the standard binomial test to personnel qualification, but applies a more stringent test for procedure qualification. The two-stage test is intended to eliminate inadequate procedures from the qualification process, preserving resources. The motivating objective for a two-stage test is to construct the first stage to eliminate a procedure whose pass rate is unacceptably low. (A procedure's pass rate is the proportion of trained examiners that would pass the personnel test when using this procedure.)

A two-stage test is ideally suited for an examination scenario where many examiners will be using a few standardized procedures, which may differ substantially in performance. If only one procedure is available, or if each examiner applies a separate own customized procedure, two-stage testing is not advantageous.

In order to construct a two-stage detection test, the same information that must be assembled for the standard binomial test is required, with the addition of a target pass rate, R_{pass}, for personnel. The target pass-rate is the pass-rate that the user considers acceptable.

The procedure qualification (1st stage) portion of the test requires that M procedure-trained examiners each pass a standard binomial detection test. The standard binomial detection test, constructed in accordance with T-1472.1, will be used for personnel qualification. The key difference is that more that one examiner is used for procedure qualification. It is important that the procedure test be conducted with examiners that are representative of the field population (and not experts). A "procedure-trained" examiner should be one that has received the standard training required for the procedure.

After the procedure has passed its test, then individual examiners are allowed to be qualified in the second stage, using the same standard binomial test. The binomial test is constructed so that critical flaws are detected with a POD of at least POD_{min} and false calls are no more than FCP_{max} with a level of confidence of α.

The number of examiners (M) used in the first stage is chosen to assure the desired pass-rate at 80% confidence (i.e. the user can be 80% sure that the actual pass-rate will be above the target value). The formula for determining the proper M is:

$$M = \frac{\log(1 - 0.80)}{\log(R_{pass})} \quad (5)$$

The table below provides the M associated with various target pass rates.

The user is completely free to choose the number of examiners (M) employed in the first stage of qualification. As one can see from the above table, the larger that M is made, the more stringent the procedure portion of the test becomes, but the higher the pass-rate becomes on the second stage of the test. In fact, for high M, the user might eliminate the second stage of the test entirely.

T-1472.3 Iterative Detection Test. This detection test is useful when the test specimens are extremely costly or limited. It is constructed in the same manner as the standard binomial test from T-1472.1, however the test presents the applicant with the same set of specimens more than once to obtain the desired sample size.

Less than 10 flaws are used, but they are used in a blind fashion. The flaws are reused in an iterative, blind, and random process. This is an economic way to increase the sample set size. The flawed and unflawed grading units are examined several times until the desired sample size and corresponding confidence level is reached. The specimens must be indistinguishable from each other so that each examination is independent and the test team cannot recognize the specimen or the flaws. The number of unflawed grading units must at least equal or exceed the number of flawed grading units. Table T-1472.1 may be used to determine the flaw sample size, misses, and POD for a given confidence level.

T-1480 EVALUATION

The owner, and, when applicable, the Jurisdiction, AIA, independent third party, examination vendor, or other user shall evaluate the technical justification report, and the results of the performance demonstration submitted by the administrator, to determine the acceptability

TABLE T-1472.2
REQUIRED NUMBER OF FIRST STAGE EXAMINERS vs. TARGET PASS RATE

Target Pass Rate (R_{pass})	Number of First Stage Examiners (M)
50	3
60	4
70	5
80	8
90	15
95	32

of the system. The evaluation shall be based upon the criteria established within the protocol document.

T-1490 DOCUMENTATION AND RECORDS

Documentation of the performance demonstration shall include the following:

(a) The technical justification document

(b) NDE procedures, including the essential variables applied

(c) Description of the equipment used, including the calibration records

(d) Description of the specimens used to perform the demonstration

(e) Certification of acceptable completion of the performance demonstration. The certification may be issued separately for the equipment/procedure and the individual.

ARTICLE 14
MANDATORY APPENDIX

APPENDIX I — GLOSSARY OF TERMS FOR EXAMINATION SYSTEM QUALIFICATION

I-1410 SCOPE

This Mandatory Appendix is used for the purpose of establishing standard terms and definition of terms, which appear in Article 14, Examination System Qualification.

I-1420 GENERAL REQUIREMENTS

(a) Paragraph I-1430 provides a list of terms and definitions, which are used in conjunction with Article 14, Examination System Qualification, and are Code specific.

(b) Terms and definitions associated with specific examination techniques and systems are addressed in the Mandatory Appendix applicable to those examination methods. Other terms and definitions used within the referencing Code of Construction are specific to that Code application.

I-1430 REQUIREMENTS

The following Code terms are used in conjunction with this Article:

(a) Blind Demonstration. A performance demonstration, where the examiner is presented with both flawed and non-flawed specimens which are visually indistinguishable, with the objective of proving the capability of an examination system to correctly detect and size flaw locations.

(b) Detection. When a specimen or grading unit is correctly interpreted as being flawed.

(c) Essential Variables. A change in the examination system, which will affect the system's ability to perform in a satisfactory manner.

(d) Examination System. The personnel, procedures, and equipment collectively applied by a given examination technique to evaluate the flaw characteristics of an object of interest.

(e) False Call. When a specimen or grading unit is incorrectly interpreted as being flawed or unflawed.

(f) False Call Probability (FCP). The percentage resulting from dividing the number of false calls by the number of specimens or grading units examined.

(g) Grading Unit. A prepared specimen, or designated interval (e.g., length) within a specimen, having known flaw characteristics, which is used to evaluate the performance of an examination system through demonstration.

(h) Level of Rigor. The level of confidence to which a given examination system must be demonstrated, based upon factors such as user needs, damage mechanism, and level of risk. There are three levels of rigor: low, intermediate, and high (see T-1424).

(i) Non-Blind Demonstration. A performance demonstration where the examiner is presented with test pieces containing clearly identifiable flaw locations of known sizes, with the objective of proving the capability of an examination system to correctly detect and size flaw locations.

(j) Nonessential Variables. A change in the examination system, which will not affect the system's ability to perform in a satisfactory manner.

(k) Performance Demonstration. A demonstration of the capabilities of an examination system to accurately evaluate a specimen with known flaw characteristics in an environment simulating field conditions.

(l) Probability of Detection (POD). The percentage resulting from dividing the number of detections by the number of flawed specimens or grading units examined. POD indicates the probability that an examination system will detect a given flaw.

(m) Qualification. Successful documentation of an examination system's ability to demonstrate established qualification objectives at the required level of rigor, in compliance with the requirements of this Article.

A06

ARTICLE 15
ALTERNATING CURRENT FIELD MEASUREMENT TECHNIQUE (ACFMT)

T-1510 SCOPE

(a) This Article describes the technique to be used when examining welds for linear type discontinuities 1/4 in. (6 mm) and greater in length utilizing the Alternating Current Field Measurement Technique (ACFMT).

(b) When specified by the referencing Code Section, the ACFMT examination technique in this Article shall be used. In general, this Article is in conformance with SE-2261, Standard Practice for Examination of Welds Using the Alternating Current Field Measurement Technique.

T-1520 GENERAL

The ACFMT method may be applied to detect cracks and other linear discontinuities on or near the surfaces of welds in metallic materials. The sensitivity is greatest for surface discontinuities and rapidly diminishes with increasing depth below the surface. In principle, this technique involves the induction of an AC magnetic field in the material surface by a magnetic yoke contained in a hand held probe, which in turn causes a uniform alternating current to flow in the material. The depth of the penetration of this current varies with material type and field frequency. Surface, or near surface, discontinuities interrupt or disturb the flow of the current creating changes in the resulting surface magnetic fields which are detected by sensor coils in the probe.

T-1521 Supplemental Requirements

ACFMT examinations of some types of welds (e.g., dissimilar, austenitic and duplex, etc.) may not be possible or may result in a larger flaw (i.e, depth) detection threshold than carbon and low alloy steel ferritic-type weld examinations because of the wide variations in magnetic permeability between the weld, heat affected zone, and plate material. It is necessary in these cases to modify and/or supplement the provisions of this Article in accordance with T-150(a). Additional items, which are necessary, are production weld mock-ups with reference notches or other discontinuities machined adjacent to, as well as within, the weld deposit.

T-1522 Written Procedure Requirements

T-1522.1 Requirements. ACFMT shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table T-1522. The written procedure shall establish a single value, or range of values, for each requirement.

T-1522.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-1522 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as an nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specificed within the written procedure shall require revision of, or an addendum to, the written procedure.

T-1530 EQUIPMENT

T-1531 Instrument

ACFMT instrument and software shall be capable of operating over a range of frequencies of from 1 to 50 kHz. The display shall contain individual time or distance-based plots of the x compound of the magnetic field B_x, parallel to the probe travel, z component of the magnetic field B_z, perpendicular to the examination surface, and a combined B_x and B_z plot (i.e., butterfly display).

T-1532 Probes

The nominal frequency shall be 5 kHz unless variables, such as materials, surface condition, or coatings require the use of other frequencies.

TABLE T-1522
REQUIREMENTS OF AN ACFMT EXAMINATION PROCEDURE

Requirement (As Applicable)	Essential Variable	Nonessential Variable
Instrument (Model and Serial No.)	X	...
Probes (Model and Serial No.)	X	...
Directions and extent of scanning	X	...
Method for sizing (length and depth) indications, when required	X	...
Coating	X	...
Coating thickness (increase only)	X	...
Personnel performance qualification requirements, when required	X	...
Surface preparation technique	...	X
Personnel qualification requirements	...	X

T-1533 Calibration Blocks

T-1533.1 General

T-1533.1.1 Block Material. The material from which the block is fabricated shall be of the same product form and material specification, or equivalent P-number grouping, of the materials being examined.

T-1533.1.2 Weld Material. Blocks fabricated out of P-3 group materials or higher shall contain a representative weld of the same A-number grouping as the weld being examined.

T-1533.1.3 Notches. Known depth and length notches shall be used to verify that the system is functioning properly.

T-1533.1.4 Quality. Prior to fabrication, the block material shall be completely examined with an ACFMT unit to assure it is free of indications that could interfere with the verification process.

T-1533.1.5 Heat Treatment. The block shall receive at least the minimum tempering treatment required by the material specification for the type and grade.

T-1533.1.6 Residual Magnetism. The block shall be checked for residual magnetism and, if necessary, demagnetized.

T-1533.2 Calibration Block. The calibration block configuration and notches shall be as shown in Fig. T-1533. Notches shall be machined at the toe (e.g., heat affected zone) and in the weld for blocks containing welds.

T-1540 MISCELLANEOUS REQUIREMENTS

T-1541 Surface Conditioning

(a) Satisfactory results are usually obtained when the surfaces are in the as-welded, as-rolled, as-cast, or as-forged condition. However, surface preparation by grinding may mask an indication and should be avoided when possible or kept to a minimum.

(b) Prior to ACFMT examination, the surface to be examined and all adjacent areas within 1 in. (25 mm) shall be free of dirt, mill scale, welding flux, oil, magnetic coatings, or other extraneous matter that could interfere with the examination.

(c) Cleaning may be accomplished by any method that does not adversely affect the part or the examination.

(d) If nonmagnetic coatings are left on the part in the area to be examined, it shall be demonstrated to show that indications can be detected through the maximum coating thickness present.

T-1542 Demagnetization

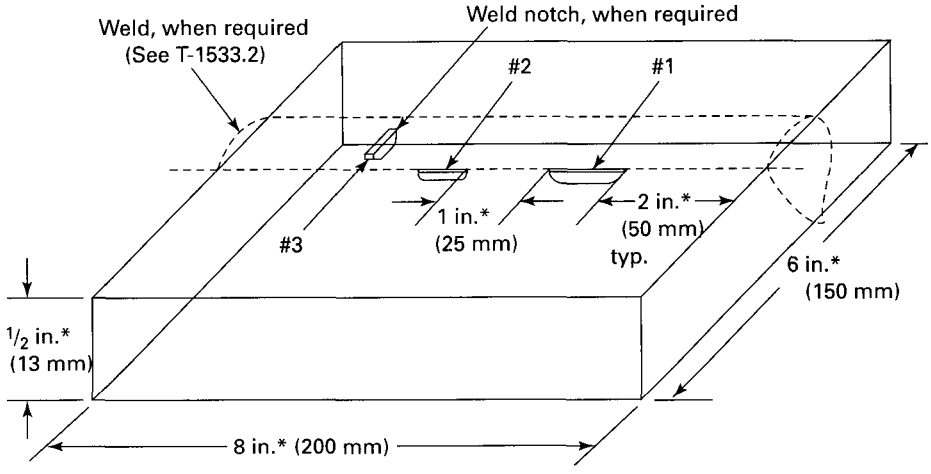
Residual magnetic fields can interfere with the ACFMT induced field and may produce false indications; therefore, ACFMT should be performed prior to a magnetic particle examination (MT). If ACFMT is performed after MT, the surface shall be demagnetized if any strong residual fields exist.

T-1543 Identification of Weld Examination Areas

(a) Weld Location. Weld locations and their identification shall be recorded on a weld map or in an identification plan.

(b) Marking. If welds are to be permanently marked, low stress stamps and/or vibrating tools may be used, unless prohibited by the referencing Code Section.

(c) Reference System. Each weld shall be located and identified by a system of reference points. The system shall permit identification of each weld and designation of regular intervals along the length of the weld.



*Minimum Dimensions

Elliptical Notch ID	Length, in. (mm)	Depth, in. (mm)	Width, in. (mm)
1	2 (50)	0.2 (5)	
2	0.25 (6)	0.1 (2.5)	0.02 (0.5) max.
3	0.25 (6)	0.1 (2.5)	

GENERAL NOTES:
(a) The tolerance on notch depth shall be ± 0.01 in. (± 0.2 mm).
(b) The tolerance on notch #1 length shall be ± 0.04 in. (± 1 mm).
(c) The tolerance on notches #2 and #3 length shall be ± 0.01 in. (± 0.2 mm).
(d) Notch shape shall be elliptical.
(e) Notch #3 only required when block contains a weld.

FIG. T-1533 ACFMT CALIBRATION BLOCK

T-1560 CALIBRATION

T-1561 General Requirements

T-1561.1 ACFMT System. Calibrations shall include the complete ACFMT system (e.g., instrument, software, computer, probe, and cable) and shall be performed prior to use of the system.

T-1561.2 Probes. The same probe to be used during the examination shall be used for calibration.

T-1561.3 Instrument Settings. Any instrument setting which affects the response from the reference notches shall be at the same setting for calibration, verification checks, and the examination.

T-1562 Calibration

T-1562.1 Warm Up. The instrument shall be turned on and allowed to warm up for the minimum time specified by the instrument manufacturer prior to calibration.

T-1562.2 Probe. The selected probe, and cable extensions if utilized, shall be connected to the instrument and the manufacturers' standard probe file loaded.

T-1562.3 Instrument Display Scan Speed. The display scan speed shall be set at the maximum rate to be used during the examination.

T-1562.4 Probe Scanning Rate. The instrument shall be calibrated by passing the probe over the notches in the calibration block and noting the responses. The nose of the probe shall be orientated parallel to the notch length and shall maintain contact with surface being examined. The probe scan rate shall not exceed that which displays a butterfly loop from the notch #1 of 50% (±10%) of full scale height and 175% (±20%) of full scale width and that also can readily detect a signal response from the smaller notch.

T-1562.5 Probe Sensitivity. When the requirements of T-1562.4 cannot be met, the probe sensitivity shall be adjusted, a different probe file loaded, or another probe selected and the notches again scanned per T-1562.4.

T-1563 Peformance Confirmation

T-1563.1 System Changes. When any part of the examination system is changed, a verification check shall be made on the calibration block to verify that the settings satisfy the requirements of T-1562.2.

T-1563.2 Periodic Checks. A verification check shall be made at the finish of each examination or series of similar examinations, and when examination personnel are changed. The response from notch #1 shall not have changed by more than 10% in either the B_x or B_z response. When the sensitivity has changed by more than 10%, all data since the last valid verification check shall be marked void or deleted and the area covered by the voided data shall be reexamined.

T-1570 EXAMINATION

T-1571 General Examination Requirements

T-1571.1 Rate of Probe Movement. The maximum instrument scan speed and probe scanning rate shall be as determined in T-1562.4.

T-1571.2 Probe Contact. The probe shall be kept in contact with the examination surface during scanning.

T-1571.3 Direction of Field. At least two separate examinations shall be performed on each area, unless otherwise specified by the referencing Code Section. During the second examination, the probe shall be positioned perpendicular to that used during the first examination.

T-1572 Examination Coverage

The weld to be scanned shall be examined by placing the probe at the toe of the weld with the nose of the probe parallel to the longitudinal direction of the weld. The probe shall then be moved parallel to and along the weld toe. A second longitudinal scan shall be performed along the opposite toe of the weld. These two scans shall then be repeated per T-1571.3. Unless demonstrated otherwise, if the width of the weld is wider than $^3/_4$ in. (19 mm), an additional set of scans shall be performed along the centerline of the weld.

T-1573 Overlap

The overlap between successive probe incremental scans shall be 1 in. (25 mm) minimum.

T-1574 Interpretation

The interpretation shall identify if an indication is false, nonrelevant, or relevant. False and nonrelevant indications shall be proven false or nonrelevant. Interpretation shall be carried out to identify the location and extent of the discontinuity and whether it is linear or nonlinear. Determination of discontinuity size (length and depth) is not required unless specified by the referencing Code Section.

T-1580 EVALUATION

All indications shall be evaluated in terms of the acceptance standards of the referencing Code Section.

T-1590 DOCUMENTATION

T-1591 Recording Indication

T-1591.1 Nonrejectable Indications. Nonrejectable indications shall be recorded as specified by the referencing Code Section.

T-1591.2 Rejectable Indications. Rejectable indications shall be recorded. As a minimum, the extent and location shall be recorded.

T-1592 Examination Record

For each examination, the following information shall be recorded:

(a) procedure identification and revision;

(b) ACFMT instrument identification (including manufacturers' serial number);

(c) software identification and revision;

(d) probe identification (including manufacturers' serial number and frequency);

(e) probe file identification and revision;

(f) calibration block identification;

(g) identification and location of weld or surface examined;

(h) map or record of rejectable indications detected or areas cleared;

(i) areas of restricted access or inaccessible welds;

(j) examination personnel identity and, when required by the referencing Code Section, qualification level; and

(k) date of examination.

T-1593 Report

A report of the examination shall be made. The report shall include those records indicated in T-1591 and T-1592. The report shall be filed and maintained in accordance with the referencing Code Section.

T-1594 Performance Demonstration

Performance demonstration, when required by the referencing Code Section, shall be documented.

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ARTICLE 16
MAGNETIC FLUX LEAKAGE (MFL) EXAMINATION

T-1610 SCOPE

This Article describes the Magnetic Flux Leakage (MFL) examination method equipment requirements applicable for performing MFL examinations on coated and uncoated ferromagnetic materials from one surface. MFL is used in the examination of tube and piping to find unwelded areas of longitudinal weld joints. It is also used as a post construction examination method to evaluate the condition of plate materials, such as storage tank floors, and piping for corrosion or other forms of degradation. Other imperfections that may be detected are cracks, seams, incomplete fusion, incomplete penetration, dents, laps, and nonmetallic inclusions, etc.

When this Article is specified by a referencing Code Section, the MFL method described in this Article shall be used together with Article 1, General Requirements.

T-1620 GENERAL

T-1621 Personnel Qualification Requirements

The user of this Article shall be responsible for documented training, qualification, and certification of personnel performing MFL examination. Personnel performing supplemental examinations, such as ultrasonic (UT) examinations, shall be qualified in accordance with the referencing Code Section.

T-1622 Equipment Qualification Requirements

The equipment operation shall be demonstrated by successfully completing the unit verification and function tests outlined as follows.

T-1622.1 Reference Specimen. All MFL examinations shall have a reference plate or pipe section to ensure the equipment is performing in accordance with the manufacturer's specifications prior to use. The reference specimen for plate shall consist of a plate that is made from a material of the same nominal thickness, product form, and composition as the component to be examined. The plate specimen shall have notches or other discontinuities machined into the bottom of the plate, as shown in Fig. T-1622.1.1. The reference specimen for pipe or tubing shall consist of a pipe or tube that is made from a material of the same nominal pipe or tube sizes, product form, and composition as the component to be examined. The pipe or tube specimen shall have notch discontinuities machined into the inside and outside surfaces as shown in Fig. T-1622.1.2. The depths and widths of the artificial discontinuities should be similar to the sizes and physical characteristics of discontinuities to be detected. If nonmagnetic coatings or temporary coverings will be present during the examination, the reference specimen shall be coated or covered with the nonmagnetic coatings or covers representative of the maximum thickness that will be encountered during the examination.

T-1622.2 System Verification and Function Checks. The manufacturer's verification procedure shall be conducted initially to ensure that the system is functioning as designed. The functional check shall be made by scanning the reference plate over the range of scanning speeds to be utilized during the examination. Equipment settings shall be documented.

T-1622.3 Performance Confirmation. A functional check shall be conducted at the beginning and end of each examination, every 8 hr, or when equipment has malfunctioned and been repaired. If it is determined that the equipment is not functioning properly, needed adjustments shall be made and all areas examined since the last performance check shall be reexamined.

T-1623 Written Procedure Requirements

T-1623.1 Requirements. MFL examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table T-1623. The written procedure shall establish a single value, or range of values, for each requirement.

The procedure shall address, as a minimum, the identification of imperfections, reference materials used to set up equipment, location and mapping of imperfections, and the extent of coverage. The procedure shall address the field strength of the magnets, the functioning of the sensors, and the operation of the signal-processing unit.

T-1670 EVALUATION

All indications shall be evaluated in accordance with the referencing Code Section.

T-1680 DOCUMENTATION

A report of the examination shall contain the following information:

(a) plate material specification, nominal wall thickness, pipe diameter, as applicable;

(b) description, such as drawing/sketches, documenting areas examined, and/or areas inaccessible;

(c) identification of the procedure used for the examination;

(d) system detection sensitivity (minimum size of imperfections detectable);

(e) location, depth, and type of all imperfections that meet or exceed the reporting criteria;

(f) examination personnel identity and, when required by referencing Code Section, qualification level;

(g) model and serial number of equipment utilized for the examination, including supplemental equipment;

(h) date and time of examination;

(i) date and time of performance verification checks; and

(j) supplemental methods utilized and reference to associated reports.

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ARTICLE 17
REMOTE FIELD TESTING (RFT) EXAMINATION METHOD

T-1710 SCOPE

(a) This Article contains the techniques and requirements for Remote Field Testing (RFT) examination and equipment.

(b) The requirements of Article 1, General Requirements, apply when a referencing Code Section requires RFT examination.

(c) Definition of terms for RFT examinations appear in Article 1, Appendix I, Glossary of Terms for Nondestructive Examination, Subsection B, Article 26, SE-2096, In Situ Examination of Ferromagnetic Heat Exchanger Tubes Using Remote Field Testing, and Article 30, SE-1316, Standard Terminology for Nondestructive Examination.

(d) Article 26, SE-2096, Standard Practice for In Situ Examination of Ferromagnetic Heat Exchanger Tubes Using Remote Field Testing, shall be used as referenced in this Appendix.

T-1720 GENERAL

T-1721 Written Procedure Requirements

T-1721.1 Requirements. RFT examinations shall be performed in accordance with a written procedure which shall, as a minimum, contain the requirements listed in Table T-1721. The written procedure shall establish a single value, or range of values, for each requirement.

T-1721.2 Procedure Qualification. When procedure qualification is specified, a change of a requirement in Table T-1721 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

T-1722 Personnel Requirements

The user of this Article shall be responsible for assigning qualified personnel to perform RFT examination to the requirements of this Article. Recommendations for training and qualifying RFT system operators are described in SE-2096. Personnel performing RFT examinations shall be qualified in accordance with requirements of the referencing Code Section.

T-1730 EQUIPMENT

RFT equipment capable of operating in the absolute or differential mode (or both modes) as specified in the written procedure, together with suitable probes and a device for recording the RFT data in a format suitable for evaluation and archival storage are all essential parts of the system. The means of displaying signals shall be on a Voltage Plane (also known as an Impedance Plane, a Voltage Plane Polar Plot, and an X-Y Display). Equipment and fixtures for moving probes through tubes and for scanning may be used.

T-1750 TECHNIQUE

(a) Single or multiple frequency techniques are permitted for this examination.

(b) Following the selection of the examination frequency(ies) and the completion of the set-up using a reference standard, the probe shall be pulled through the tubes to be examined at a speed that shall be uniform and appropriate to the examination frequency, digital sampling rate, and required sensitivity to flaws. This rate of scanning shall be used to perform the examination.

T-1760 CALIBRATION

T-1761 Instrument Calibration

RFT instrumentation shall be recalibrated annually and whenever the equipment is subjected to damage and/or

TABLE T-1721
REQUIREMENTS OF AN RFT EXAMINATION PROCEDURE

Requirement (As Applicable)	Essential Variable	Nonessential Variable
Frequency(ies)	X	...
Mode (Different/Absolute)	X	...
Minimum fill factor	X	...
Probe type	X	...
Equipment manufacturer/model	X	...
Scanning speed	X	...
Identity of artificial flaw reference	X	...
Tube material, size, and grade	X	...
Data analysis technique	X	...
Procedure qualifications, when specified	X	...
Personnel qualifications	...	X
Scanning equipment/fixtures	...	X
Tube surface preparation	...	X
Data recording equipment	...	X
Tube numbering	...	X
Report format	...	X

after any major repair. When equipment has not been in use for a year or more, calibration shall be performed prior to first use. A tag or other form of documentation shall be attached to the RFT instrument with date of calibration and calibration due date shown.

T-1762 System Preparation

T-1762.1 The RFT system is set up for the examination using artificial flaws fabricated in a reference tube. The reference standard shall be in accordance with SE-2096, Fig. 4, and para. 10.5 of that document. The reference standard shall include a tube support plate fabricated in accordance with SE-2096, para. 10.6. When it is required to detect and size small volume flaws, such as corrosion pits, a second reference tube, such as the example shown in Fig. T-1762, shall be used to demonstrate adequate sensitivity. Pit depth and size selection shall be determined by the application. Pit depth tolerance shall be +0/−10%. Hole diameter tolerance shall be ±10%. The spacing of the artificial flaws shall be suitable for the coil spacing on the RFT probe to ensure that flaws or tube ends are not near the exciter(s) and detector(s) at the same time.

Tubes used as reference standards shall be of the same nominal dimensions and material type as the tubes to be examined.

T-1762.2 Where either the exact material type or dimensional matches are not available, an alternative tube may be used. A demonstration of the equivalency of the alternate reference is required. An example of demonstrating normalized response is when one of the following responses from the reference standard and the nominal tube are equal:

(a) the amplitude and angular position of a support plate indication on the voltage plane

(b) the angular difference between a support plate indication and the tube exit indication on the voltage plane

(c) the absolute phase response

T-1763 System Set-up and Calibration

T-1763.1 Differential Channels

(a) The phase rotation of the base frequency (F1) shall be adjusted so that the signal from the through-wall hole (TWH) appears approximately along the Y (vertical) axis and that the signal from the tube support plate (TSP) lies in the upper left-hand and lower right-hand quadrants. When properly adjusted, the differential signals should be displayed on a voltage plane display, such as those shown in Figs. T-1763.1(a) and T-1763.1(b)

(b) The signal response for the through-wall hole reference flaw shall be generated when pulling the probe past the hole such that the initial response is downward followed by an upward motion and then back to the null point on the voltage plane.

(c) The sensitivity shall be adjusted to produce a minimum peak-to-peak signal of approximately 50% full screen height from the through-wall hole.

(d) The response from the 20% wear groove in the reference tube should be at approximately 150 deg (as measured clockwise from the negative X-axis). See Fig.T-1763.1(a). The angular difference between the TWH response and the 20% flaw response shall be 60 deg ±10 deg. Alternate initial response angles representing artificial flaws may be used, providing the difference between the TWH response and the 20% groove response meets this criteria.

T-1763.2 Absolute Channels

(a) The signal responses for absolute channels are set up using a procedure similar to that used to set up the differential channels using the Voltage Plane display. Absolute signals will appear as half the extent of differential signals.

(b) Voltage Plane Polar Plot displays may also be used for setting up the absolute probe technique using the following procedure:

(1) Adjust the frequency(ies) and phase of the signal from the through hole in the reference standard so that it originates at 1, 0 on the polar plot display and develops by going upward and to the left at an angle between 20 deg and 120 deg measured clockwise from the X axis. The TSP signal will lie approximately parallel to the X axis.

RFT PIT REFERENCE TUBE

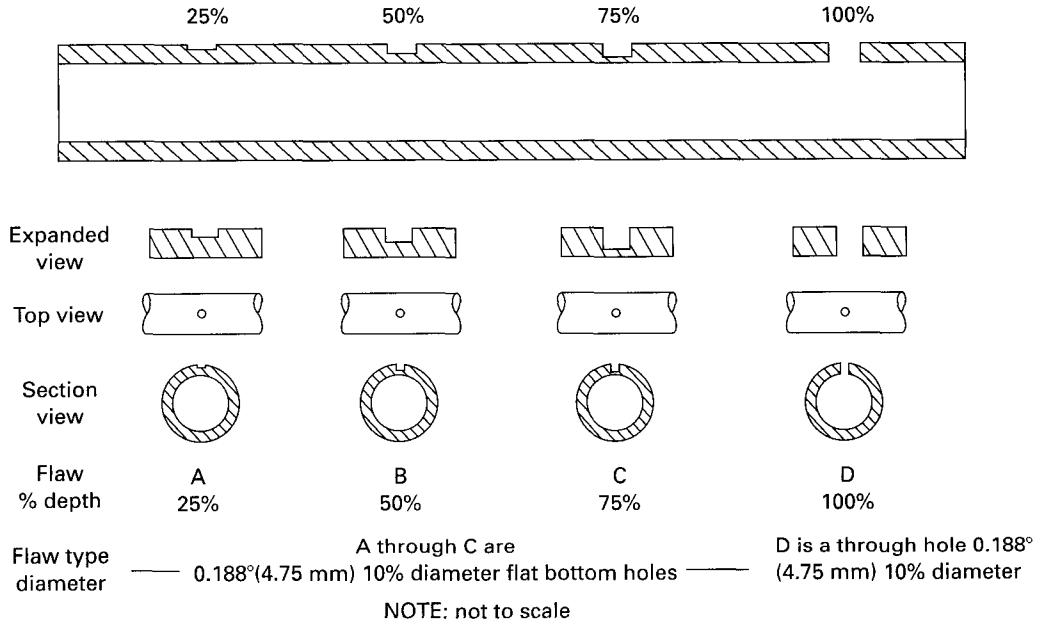


FIG. T-1762 PIT REFERENCE TUBE (TYPICAL)

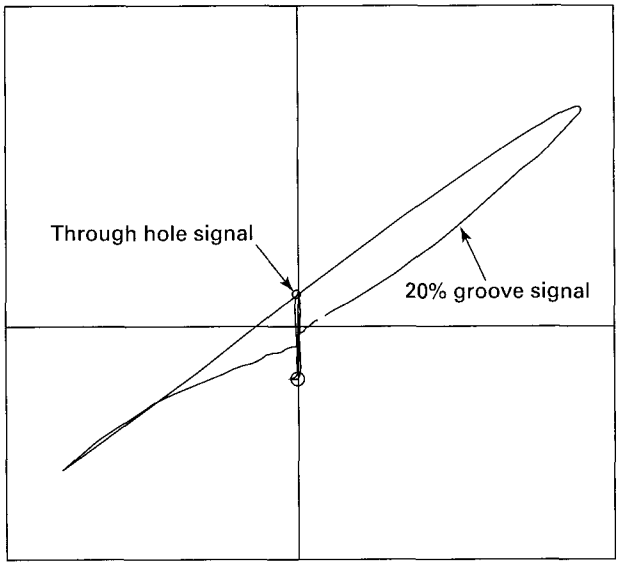


FIG. T-1763.1(a) VOLTAGE PLANE DISPLAY OF DIFFERENTIAL CHANNEL RESPONSE FOR THROUGH WALL HOLE (THROUGH HOLE SIGNAL) AND 20% GROOVE SHOWING PREFERRED ANGULAR RELATIONSHIP

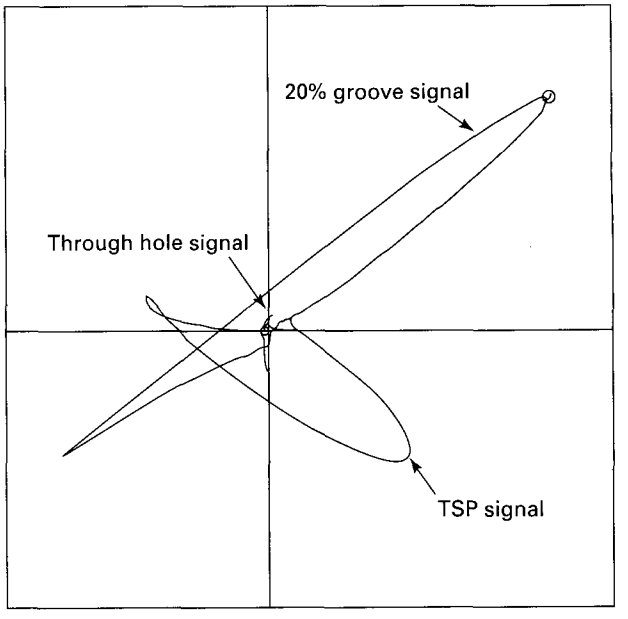


FIG. T-1763.1(b) VOLTAGE PLANE DISPLAY OF DIFFERENTIAL CHANNEL RESPONSE FOR THE TUBE SUPPORT PLATE (TSP), 20% GROOVE, AND THROUGH WALL HOLE (THROUGH HOLE SIGNAL)

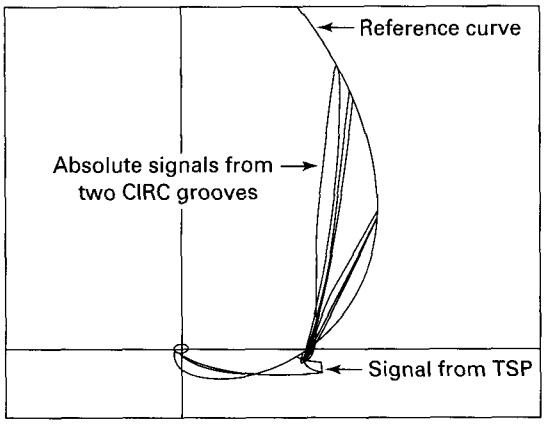


FIG. T-1763.2 REFERENCE CURVE AND THE ABSOLUTE CHANNEL SIGNAL RESPONSE FROM TWO CIRCUMFERENTIAL GROOVES AND A TUBE SUPPORT PLATE

(2) If a reference curve is used, the signals from the two 20% grooves in the reference standard should peak close to the reference curve. If they do not peak close to the reference curve, the test frequency and/or probe drive shall be adjusted until they do.

(3) Signals from flaws that are evenly displaced around the circumference of the tube, such as "general wall loss," will typically follow the reference curve. Signals from imperfections that are predominantly on one side of the tube will appear inside the reference curve. Signals from magnetic permeability variations will appear outside the reference curve. Figure T-1763.2 illustrates the Voltage Plane Polar Plot display with the signals from two circumferential grooves, a tube support plate, and the reference curve.

T-1763.3 Dual Exciter and Array Probes. Dual exciter and array probes may be used provided system performance is demonstrated by use of the reference standard. Displays used may vary from system to system.

T-1764 Auxiliary Frequency(s) Calibration Procedure

(a) Auxiliary frequencies may be used to examine tubes. They may be multiples (harmonics) of the base frequency or may be independent of the base frequency.

(b) Auxiliary frequencies may be "mixed" with the base frequency to produce an output signal that suppresses unwanted variable responses, such as those from the tube support plates.

(c) When "mixed" signals are used for flaw evaluation, they shall demonstrate sensitivity to reference standard artifical flaw with suppression of the unwanted signal. For example, the unwanted signal may be the tube support plate signal. Auxiliary frequency response and mixed signal response to the unwanted signal shall be part of the calibration record.

(d) The base frequency and auxiliary frequency(ies) response shall be recorded simultaneously.

T-1765 Calibration Confirmation

(a) Calibration of the system hardware shall be confirmed in accordance with requirements of the referencing Code Section. When not specified in the referencing Code Section, analog elements of the system shall be calibrated annually or prior to first use.

(b) Calibration shall include the complete RFT examination system. Any change of the probe, extension cables, RFT instrument, computer, or other recording instruments shall require recalibration of the system, and recalibration shall be noted on the report.

(c) Should the system be found to be out of calibration during the examination, it shall be recalibrated. The recalibration shall be noted on the report. All tubes examined since the last valid calibration shall be reexamined.

T-1766 Correlation of Signals to Estimate Depth of Flaws

The "phase angle analysis" method or the "phase lag and log-amplitude analysis" method shall be used to estimate the depth of flaws. In both cases the size (amplitude) of the signal is related to flaw surface area, and the phase angle is related to the flaw depth. The method used shall be fully documented in the examination records and the relationship between flaw dimensions and signals shall be described. One or both methods may be used for flaw depth and size estimation.

T-1766.1 Phase Angle Method. A relationship of signal phase angles to reference flaw depths shall be developed for the examination being performed.

T-1766.2 Phase-Lag Method. A relationship of phase lag angle and log-amplitude of signals from the reference standard flaws shall be developed for the examination being performed.

T-1770 EXAMINATION

T-1771 General

Data shall be recorded as the probe traverses the tube. The data may be gathered in a "timed" mode or a "distance encoded" mode. The axial location of discontinuities shall be estimated by reference to known features or by encoder measurements.

T-1772 Probe Speed

The probe speed shall be dependent on the base frequency and sample rate and shall be no faster than the speed required to obtain a clear signal from the reference standard through-wall hole, without any measurable phase shift or amplitude change of the signal.

T-1780 EVALUATION

The analysis and evaluation of examination data shall be made in accordance with the referencing Code Section.

T-1790 DOCUMENTATION

A report of the examination shall be generated. The report shall include, at a minimum, the following information:

(a) owner, location, type, serial number, and identification of component examined;

(b) size, wall thickness, material type, and configuration of installed tubes;

(c) tube numbering system;

(d) extent of examination or tubes examined and length of tubes scanned;

(e) personnel performing the examination;

(l) qualification level when required by the referencing Code Section

(f) date of examination;

(g) models, types, and serial numbers of components of the RFT system;

(h) probe model/type and extension length;

(i) all relevant instrument settings;

(j) serial number(s) of reference tube(s);

(k) procedure used — identification and revision;

(l) acceptance criteria used;

(m) identify tubes or specific regions where limited sensitivity and other areas of reduced sensitivity or other problems;

(n) results of the examination and related sketches or maps of the examined area; and

(o) complementary tests used to further investigate or confirm test results.

T-1791 Performance Demonstration Report

When procedure qualification is specified, performance demonstrations shall be documented and contain the following information:

(a) identification and revision of the procedure;

(b) identification of personnel performing and witnessing the procedure qualification;

(c) identification of the essential variable(s) when changed and the new value or range of values required for requalification;

(d) procedure qualification results; and

(e) date of performance demonstration or procedure requalification.

T-1793 Record Retention

Records shall be maintained in accordance with requirements of the referencing Code Section.

SUBSECTION B
DOCUMENTS ADOPTED BY SECTION V

ARTICLE 22
RADIOGRAPHIC STANDARDS

STANDARD GUIDE FOR RADIOGRAPHIC EXAMINATION

A06

SE-94

(Identical with ASTM Specification E 94-04)

1. Scope

1.1 This guide covers satisfactory X-ray and gamma-ray radiographic examination as applied to industrial radiographic film recording. It includes statements about preferred practice without discussing the technical background which justifies the preference. A bibliography of several textbooks and standard documents of other societies is included for additional information on the subject.

1.2 This guide covers types of materials to be examined; radiographic examination techniques and production methods; radiographic film section, processing, viewing, and storage; maintenance of inspection records; and a list of available reference radiograph documents.

NOTE 1 — Further information is contained in Guide E 999, Practice E 1025, Test Methods E 1030, and E 1032.

1.3 *Interpretation and Acceptance Standards* — Interpretation and acceptance standards are not covered by this guide, beyond listing the available reference radiograph documents for casting and welds. Designation of accept-reject standards is recognized to be within the cognizance of product specifications and generally a matter of contractual agreement between producer and purchaser.

1.4 *Safety Practices* — Problems of personnel protection against X-rays and gamma rays are not covered by this document. For information on this important aspect of radiography, reference should be made to the current document of the National Committee on Radiation Protection and Measurement, Federal Register, U.S. Energy Research and Development Administration, National Bureau of Standards, and to state and local regulations, if such exist. For specific radiation safety information

refer to NIST Handbook ANSI 43.3, 21 CFR 1020.40, and 29 CFR 1910.1096 or state regulations for agreement states.

1.5 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (See 1.4.)

1.6 If an NDT agency is used, the agency shall be qualified in accordance with Practice E 543.

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing

E 746 Test Method for Determining the Relative Image Quality Response of Industrial Radiographic Film

E 747 Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E 801 Practice for Controlling Quality of Radiological Examination of Electronic Devices

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E 1030 Test Method for Radiographic Examination of Metallic Castings

E 1032 Test Method for Radiographic Examination of Weldments

E 1079 Practice for Calibration of Transmission Densitometers

E 1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films

E 1316 Terminology for Nondestructive Examinations

E 1390 Guide for Illuminators Used for Viewing Industrial Radiographs

E 1735 Test Method for Determining Relative Image Quality of Industrial Radiographic Film Exposed to X-Radiation from 4 to 25 MV

E 1742 Practice for Radiographic Examination

E 1815 Test Method for Classification of Film Systems for Industrial Radiography

2.2 *ANSI Standards:*

PH1.41 Specifications for Photographic Film for Archival Records, Silver-Gelatin Type, on Polyester Base

PH2.22 Methods for Determining Safety Times of Photographic Darkroom Illumination

PH4.8 Methylene Blue Method for Measuring Thiosulfate and Silver Densitometric Method for Measuring Residual Chemicals in Films, Plates, and Papers

T9.1 Imaging Media (Film) — Silver-Gelatin Type Specifications for Stability

T9.2 Imaging Media — Photographic Processed Film, Plate, and Paper — Filing Enclosures and Storage Containers

2.3 *Federal Standards:*

Title 21, Code of Federal Regulations (CFR) 1020.40, Safety Requirements of Cabinet X-Ray Systems

Title 29, Code of Federal Regulations (CFR) 1910.96, Ionizing Radiation (X-Rays, RF, etc.)

2.4 *Other Document:*

NBS Handbook ANSI N43.3 General Radiation Safety Installations Using NonMedical X-Ray and Sealed Gamma Sources up to 10 MeV

3. Terminology

3.1 *Definitions* — For definitions of terms used in this guide, refer to Terminology E 1316.

4. Significance and Use

4.1 Within the present state of the radiographic art, this guide is generally applicable to available materials, processes, and techniques where industrial radiographic films are used as the recording media.

4.2 *Limitations* — This guide does not take into consideration special benefits and limitations resulting from the use of nonfilm recording media or readouts such as paper, tapes, xeroradiography, fluoroscopy, and electronic image intensification devices. Although reference is made to documents that may be used in the identification and grading, where applicable, of representative discontinuities in common metal castings and welds, no attempt has been made to set standards of acceptance for any material or production process. Radiography will be consistent in sensitivity and resolution only if the effect of all details of techniques, such as geometry, film, filtration, viewing, etc., is obtained and maintained.

5. Quality of Radiographs

5.1 To obtain quality radiographs, it is necessary to consider as a minimum the following list of items. Detailed information on each item is further described in this guide.

5.1.1 Radiation source (X-ray or gamma),

5.1.2 Voltage selection (X-ray),

5.1.3 Source size (X-ray or gamma),

5.1.4 Ways and means to eliminate scattered radiation,

5.1.5 Film system class,

5.1.6 Source to film distance,

5.1.7 Image quality indicators (IQIs)

5.1.8 Screens and filters,

5.1.9 Geometry of part or component configuration,

5.1.10 Identification and location markers, and

5.1.11 Radiographic quality level.

6. Radiographic Quality Level

6.1 Information on the design and manufacture of image quality indicators (IQIs) can be found in Practices E 747, E 801, E 1025, and E 1742.

6.2 The quality level usually required for radiography is 2% (2-2T when using hole type IQI) unless a higher or lower quality is agreed upon between the purchaser and the supplier. At the 2% subject contrast level, three quality levels of inspection, 2-1T, 2-2T, and 2-4T, are available through the design and application of the IQI (Practice E 1025, Table 1). Other levels of inspection are available in Practice E 1025, Table 1. The level of inspection specified should be based on the service requirements of the product. Great care should be taken in specifying quality levels 2-1T, 1-1T, and 1-2T by first determining that these quality levels can be maintained in production radiography.

NOTE 2 — The first number of the quality level designation refers to IQI thickness expressed as a percentage of specimen thickness; the second number refers to the diameter of the IQI hole that must be visible on the radiograph, expressed as a multiple of penetrameter thickness, *T*.

6.3 If IQIs of material radiographically similar to that being examined are not available, IQIs of the required dimensions but of a lower-absorption material may be used.

6.4 The quality level required using wire IQIs shall be equivalent to the 2-2T level of Practice E 1025 unless a higher or lower quality level is agreed upon between purchaser and supplier. Table 4 of Practice E 747 gives a list of various hole-type IQIs and the diameter of the wires of corresponding EPS with the applicable 1T, 2T, and 4T holes in the plaque IQI. Appendix XI of Practice E 747 gives the equation for calculating other equivalencies, if needed.

TABLE 1
TYPICAL STEEL HVL THICKNESS IN INCHES (MM) FOR COMMON ENERGIES

Energy	Thickness, in. (mm)
120 kV	0.10 (2.5)
150 kV	0.14 (3.6)
200 kV	0.20 (5.1)
250 kV	0.25 (6.4)
400 kV (Ir 192)	0.35 (8.9)
1 Mv	0.57 (14.5)
2 Mv (Co 60)	0.80 (20.3)
4 Mv	1.00 (25.4)
6 Mv	1.15 (29.2)
10 Mv	1.25 (31.8)
16 Mv and higher	1.30 (33.0)

7. Energy Selection

7.1 X-ray energy affects image quality. In general, the lower the energy of the source utilized the higher the achievable radiographic contrast, however, other variables such as geometry and scatter conditions may override the potential advantage of higher contrast. For a particular energy, a range of thicknesses, which are a multiple of the half value layer, may be radiographed to an acceptable quality level utilizing a particular X-ray machine or gamma ray source. In all cases the specified IQI (penetrameter) quality level must be shown on the radiograph. In general, satisfactory results can normally be obtained for X-ray energies between 100 kV to 500 kV in a range between 2.5 to 10 half value layers (HVL) of material thickness (see Table 1). This range may be extended by as much as a factor of 2 in some situations for X-ray energies in the 1 to 25 MV range primarily because of reduced scatter.

8. Radiographic Equivalence Factors

8.1 The radiographic equivalence factor of a material is that factor by which the thickness of the material must be multiplied to give the thickness of a "standard" material (often steel) which has the same absorption. Radiographic equivalence factors of several of the more common metals are given in Table 2, with steel arbitrarily assigned a factor of 1.0. The factors may be used:

TABLE 2
APPROXIMATE RADIOGRAPHIC EQUIVALENCE FACTORS FOR SEVERAL METALS
(RELATIVE TO STEEL)

Metal	Energy Level									
	100 kV	150 kV	220 kV	250 kV	400 kV	1 MV	2 MV	4 to 25 MV	^{192}Ir	^{60}Co
Magnesium	0.05	0.05	0.08							
Aluminum	0.08	0.12	0.18						0.35	0.35
Aluminum alloy	0.10	0.14	0.18						0.35	0.35
Titanium		0.54	0.54		0.71	0.9	0.9	0.9	0.9	0.9
Iron/all steels	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Copper	1.5	1.6	1.4	1.4	1.4	1.1	1.1	1.2	1.1	1.1
Zinc		1.4	1.3		1.3			1.2	1.1	1.0
Brass		1.4	1.3		1.3	1.2	1.1	1.0	1.1	1.0
Inconel X		1.4	1.3	1.3		1.3	1.3	1.3	1.3	1.3
Monel	1.7		1.2							
Zirconium	2.4	2.3	2.0	1.7	1.5	1.0	1.0	1.0	1.2	1.0
Lead	14.0	14.0	12.0			5.0	2.5	2.7	4.0	2.3
Hafnium			14.0	12.0	9.0	3.0				
Uranium			20.0	16.0	12.0	4.0		3.9	12.6	3.4

8.1.1 To determine the practical thickness limits for radiation sources for materials other than steel, and

8.1.2 To determine exposure factors for one metal from exposure techniques for other metals.

9. Film

9.1 Various industrial radiographic film are available to meet the needs of production radiographic work. However, definite rules on the selection of film are difficult to formulate because the choice depends on individual user requirements. Some user requirements are as follows: radiographic quality levels, exposure times, and various cost factors. Several methods are available for assessing image quality levels (see Test Method E 746, and Practices E 747 and E 801). Information about specific products can be obtained from the manufacturers.

9.2 Various industrial radiographic films are manufactured to meet quality level and production needs. Test Method E 1815 provides a method for film manufacturer classification of film systems. A film system consists of the film and associated film processing system. Users may obtain a classification table from the film manufacturer for the film system used in production radiography. A choice of film class can be made as provided in Test Method E 1815. Additional specific details regarding classification of film systems is provided in Test Method 1815. ANSI Standards PH1.41, PH4.8, T9.1, and T9.2 provide specific details and requirements for film manufacturing.

10. Filters

10.1 *Definition* — Filters are uniform layers of material placed between the radiation source and the film.

10.2 *Purpose* — The purpose of filters is to absorb the softer components of the primary radiation, thus resulting in one or several of the following practical advantages:

10.2.1 Decreasing scattered radiation, thus increasing contrast.

10.2.2 Decreasing undercutting, thus increasing contrast.

10.2.3 Decreasing contrast of parts of varying thickness.

10.3 *Location* — Usually the filter will be placed in one of the following two locations:

10.3.1 As close as possible to the radiation source, which minimizes the size of the filter and also the contribution of the filter itself to scattered radiation to the film.

10.3.2 Between the specimen and the film in order to absorb preferentially the scattered radiation from the specimen. It should be noted that lead foil and other metallic screens (see 13.1) fulfill this function.

10.4 *Thickness and Filter Material* — The thickness and material of the filter will vary depending upon the following:

10.4.1 The material radiographed.

10.4.2 Thickness of the material radiographed.

10.4.3 Variation of thickness of the material radiographed.

10.4.4 Energy spectrum of the radiation used.

10.4.5 The improvement desired (increasing or decreasing contrast). Filter thickness and material can be calculated or determined empirically.

11. Masking

11.1 Masking or blocking (surrounding specimens or covering thin sections with an absorptive material) is helpful in reducing scattered radiation. Such a material can also be used to equalize the absorption of different sections, but the loss of detail may be high in the thinner sections.

12. Back-Scatter Protection

12.1 Effects of back-scattered radiation can be reduced by confining the radiation beam to the smallest practical cross section and by placing lead behind the film. In some cases either or both the back lead screen and the lead contained in the back of the cassette or film holder will furnish adequate protection against back-scattered radiation. In other instances, this must be supplemented by additional lead shielding behind the cassette or film holder.

12.2 If there is any question about the adequacy of protection from back-scattered radiation, a characteristic symbol [frequently a $^{1}/_{8}$-in. (3.2-mm) thick letter *B*] should be attached to the back of the cassette or film holder, and a radiograph made in the normal manner. If the image of this symbol appears on the radiograph as a lighter density than background, it is an indication that protection against back-scattered radiation is insufficient and that additional precautions must be taken.

13. Screens

13.1 *Metallic Foil Screens:*

13.1.1 Lead foil screens are commonly used in direct contact with the films, and, depending upon their thickness, and composition of the specimen material, will exhibit an intensifying action at as low as 90 kV. In addition, any screen used in front of the film acts as a filter (Section 10) to preferentially absorb scattered radiation arising from the specimen, thus improving radiographic quality. The selection of lead screen thickness, or for that matter, any metallic screen thickness, is subject to the same considerations as outlined in 10.4. Lead screens lessen the scatter reaching the film regardless of whether the screens permit a decrease or necessitate an increase in the radiographic exposure. To avoid image unsharpness due to screens, there should be intimate contact between the lead screen and the film during exposure.

13.1.2 Lead foil screens of appropriate thickness should be used whenever they improve radiographic quality or penetrameter sensitivity or both. The thickness of the front lead screens should be selected with care to avoid excessive filtration in the radiography of thin or light alloy materials, particularly at the lower kilovoltages. In general, there is no exposure advantage to the use of 0.005 in. in front and back lead screens below 125 kV in the radiography of $^{1}/_{4}$-in. (6.35-mm) or lesser thickness steel. As the kilovoltage is increased to penetrate thicker sections of steel, however, there is a significant exposure advantage. In addition to intensifying action, the back lead screens are used as protection against back-scattered radiation (see Section 12) and their thickness is only important for this function. As exposure energy is increased to penetrate greater thicknesses of a given subject material, it is customary to increase lead screen thickness. For radiography using radioactive sources, the minimum thickness of the front lead screen should be 0.005 in. (0.13 mm) for iridium-192, and 0.010 in. (0.25 mm) for cobalt-60.

13.2 *Other Metallic Screen Materials:*

13.2.1 Lead oxide screens perform in a similar manner to lead foil screens except that their equivalence in lead foil thickness approximates 0.0005 in. (0.013 mm).

13.2.2 Copper screens have somewhat less absorption and intensification than lead screens, but may provide somewhat better radiographic sensitivity with higher energy above 1 MV.

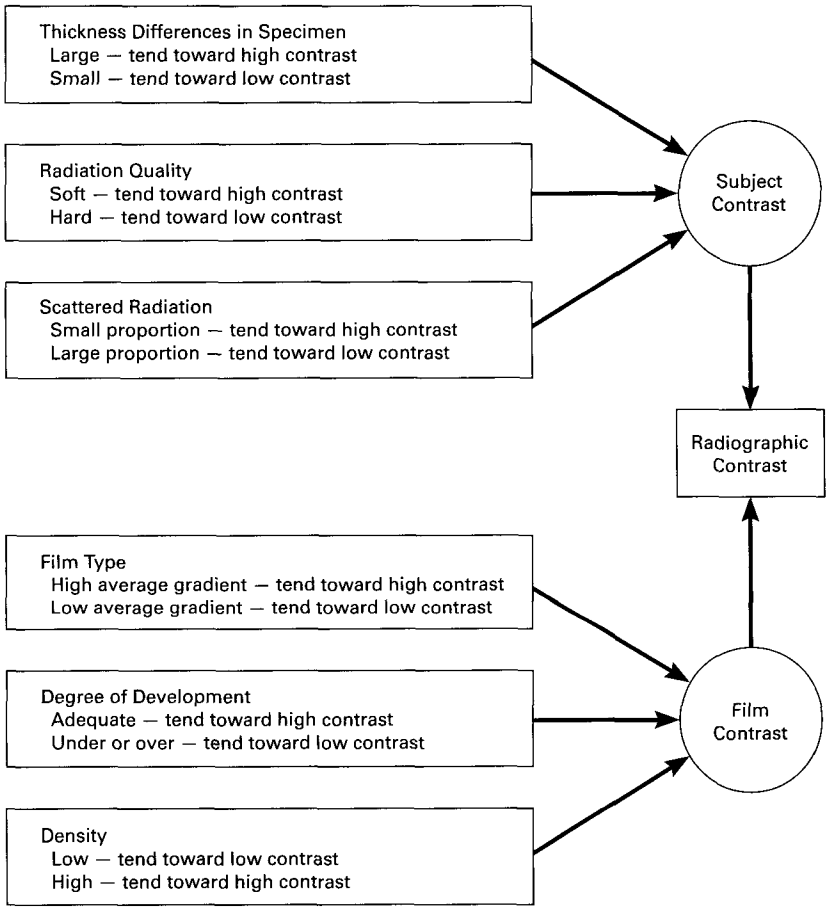
13.2.3 Gold, tantalum, or other heavy metal screens may be used in cases where lead cannot be used.

13.3 *Fluorescent Screens* — Fluorescent screens may be used as required providing the required image quality is achieved. Proper selection of the fluorescent screen is required to minimize image unsharpness. Technical information about specific fluorescent screen products can be obtained from the manufacturers. Good film-screen contact and screen cleanliness are required for successful use of fluorescent screens. Additional information on the use of fluorescent screens is provided in Appendix X1.

13.4 *Screen Care* — All screens should be handled carefully to avoid dents and scratches, dirt, or grease on active surfaces. Grease and lint may be removed from lead screens with a solvent. Fluorescent screens should be cleaned in accordance with the recommendations of the manufacturer. Screens showing evidence of physical damage should be discarded.

14. Radiographic Contrast

14.1 The various radiation intensities that penetrate an object are rendered as different photographic densities in a radiograph. Using transmitted or reflected light to view a radiograph, an observed change in film density over a background is defined as contrast. Radiographic contrast depends mostly upon subject contrast and film gradient.



GENERAL NOTE: The maximum usable density on Class 1, 2, and 3 film depends on the illuminator available.

FIG. 1 EFFECTS OF CHANGES IN VARIABLES ON QUALITY OF RADIOGRAPHY

14.2 Subject contrast is the ratio of radiation intensities transmitted by two selected portions of a specimen.

14.3 The film gradient is the value of the slope of the tangent line drawn to a particular density point on the characteristic curve to the abscissa. Film manufacturers can furnish characteristic curves of their products.

14.4 The quality of radiography is influenced by many variables; the effects of changes in some of these variables are illustrated in Fig. 1.

15. Geometry

15.1 The source to film distance necessary to reduce geometric unsharpness to a negligible amount depends upon the film or film-screen combinations, focal-spot size, and object–film distance. Geometric unsharpness is given [see Fig. 2(a)] by the equation:

$$U_g = Ft/d_o$$

where:

U_g = geometric unsharpness,
F = maximum projected dimension of radiation source,
t = distance from source side of specimen to film, and
d_o = source–object distance.

NOTE 3 — d_o and t must be in the same units of measure; the units of U_g will be in the same units as F.

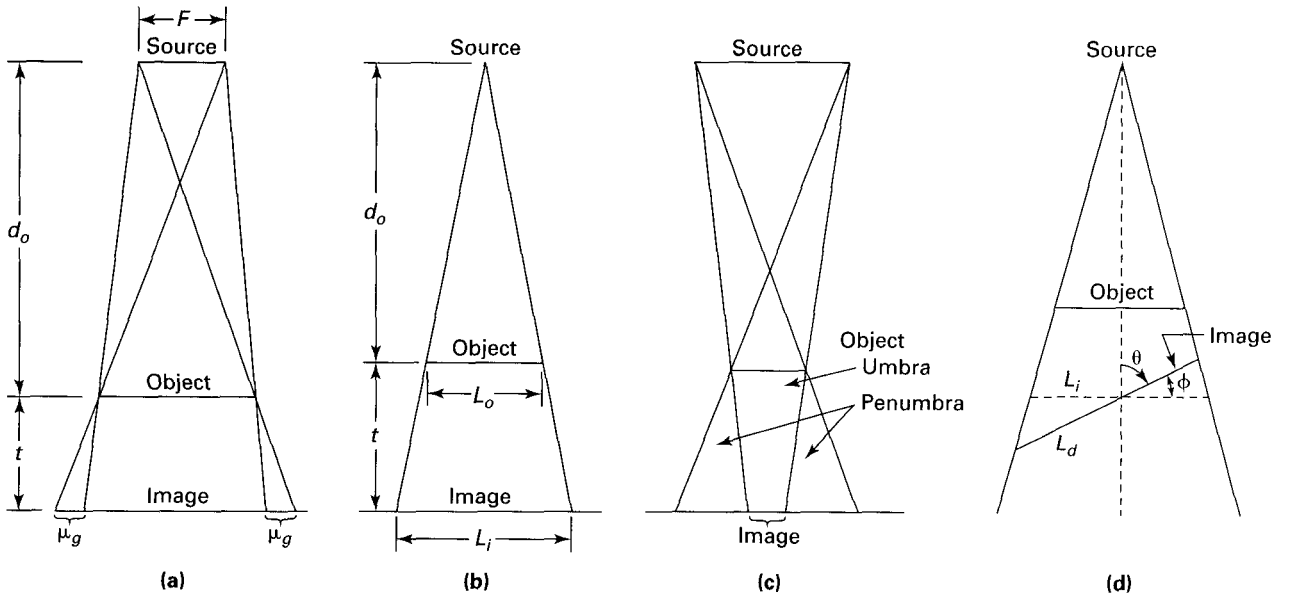
NOTE 4 — A nomogram for the determination of U_g is given in Fig. 3 (inch-pound units). Fig. 4 represents a nomogram in metric units.

Example:

Given:

Source–object distance (d_o) = 40 in.,
Source size (F) = 500 mils, and
Source side of specimen to film distance (t) = 1.5 in.

Draw a straight line (dashed in Fig. 3) between 500 mils on the F scale and 1.5 in. on the t scale. Note the point on intersection (P) of this line



(a) Geometric Unsharpness
d_o = source to object distance
t = object to film distance
F = greatest dimension of source or focal spot
$U_g = Ft/d_o$

(b) Object or feature larger than the source
$L_i - L_o = \Delta L = 2t \times \tan {}^1/_2\,\theta$
$\Delta L/L_o \times 100$ = percentage enlargement

(c) Radiographic reduction
Image will be smaller than object or feature

(d) Radiographic Distortion
Legend for (d)
L_i = dimension of undistorted image
L_d = dimension of distorted image
$L_d - L_i = \Delta L$
Percentage distortion = $(\Delta L/L_i) \times 100$

(a) Geometric Unsharpness
Legend for (a) and (b)
d_o = source to object distance
t = object to film distance
L_o = dimension of object
L_i = dimension of image
$U_g = Ft/d_o$

(b) Object or feature larger than the source
$L_i - L_o = \Delta L = 2t \times \tan {}^1/_2\,\theta$
$\Delta L/L_o \times 100$ = percentage enlargement

(c) Object or feature smaller than source
Image will be smaller than object or feature

(d) Radiographic Distortion Legend for (d)
L_i = dimension of undistorted image
L_d = dimension of distorted image
$L_d - L_i = \Delta L$
Percentage distortion = $(\Delta L/L_i) \times 100$

FIG. 2 EFFECTS OF OBJECT-FILM GEOMETRY

with the pivot line. Draw a straight line (solid in Fig. 3) from 40 in. on the d_o scale through point P and extend to the U_g scale. Intersection of this line with the U_g scale gives geometrical unsharpness in millimetres, which in the example is 19 mils.

Inasmuch as the source size, F, is usually fixed for a given radiation source, the value of U_g is essentially controlled by the simple d_o/t ratio.

15.2 The radiographic image of an object or feature within an object may be larger or smaller than the object or feature itself, because the penumbra of the shadow is rarely visible in a radiograph. Therefore, the image will be larger if the object or feature is larger than the source of radiation, and smaller if object or feature is smaller than the source. The degree of reduction or enlargement will depend on the source-to-object and object-to-film distances, and on the relative sizes of the source and the object or feature [Fig. 2*(b)* and *(c)*].

15.3 The direction of the central beam of radiation should be perpendicular to the surface of the film whenever possible. The object image will be distorted if the fiilm is not aligned perpendicular to the central beam. Different parts of the object image will be distorted different amount depending on the extent of the film to central beam offset [Fig. 2*(d)*].

15.4 Geometric unsharpness (Ug) can have a significant effect on the quality of the radiograph, therefore source to film distance (SFD) selection is important. The

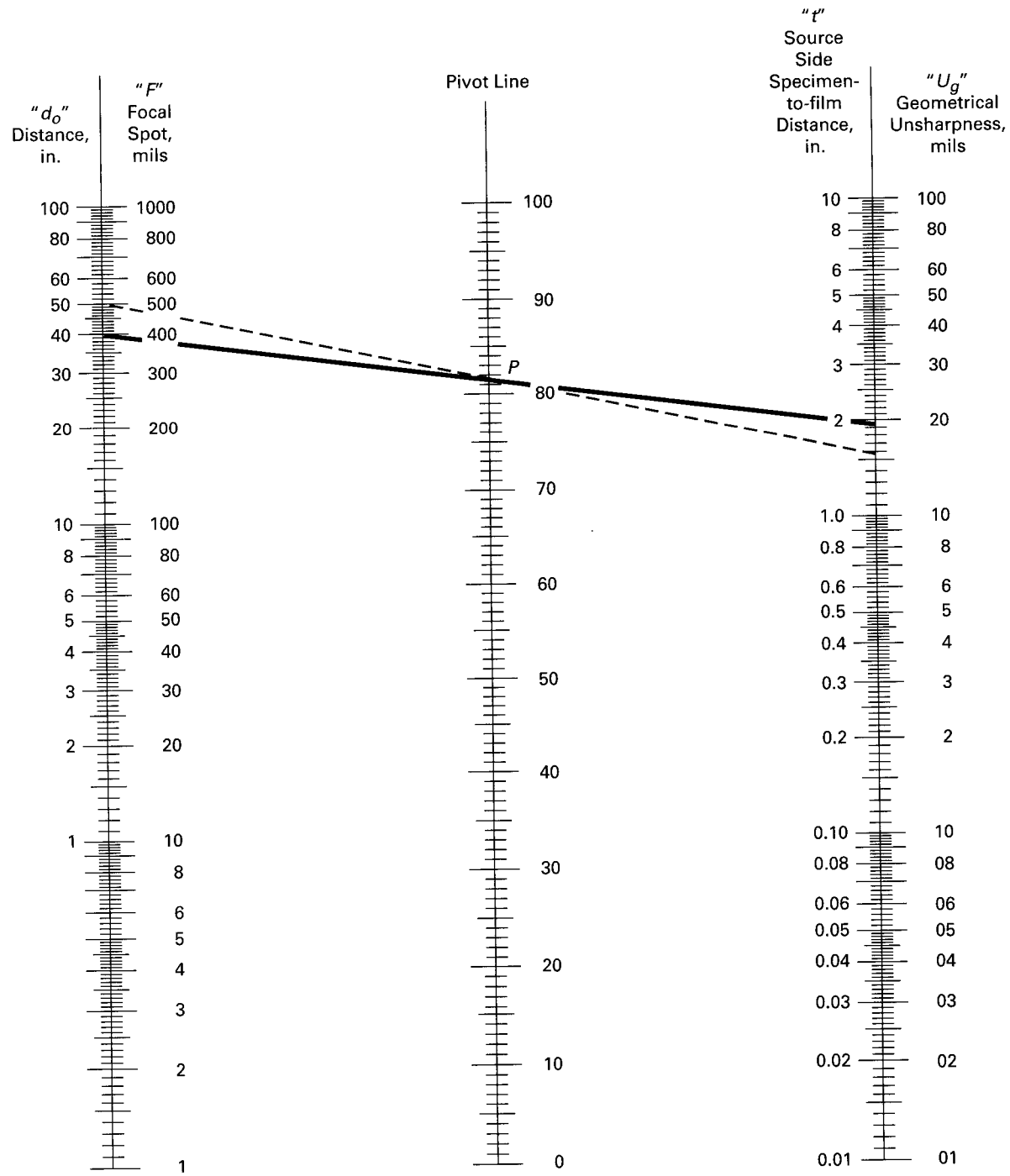


FIG. 3 NOMOGRAM FOR DETERMINING GEOMETRICAL UNSHARPNESS
(Inch-Pound Units)

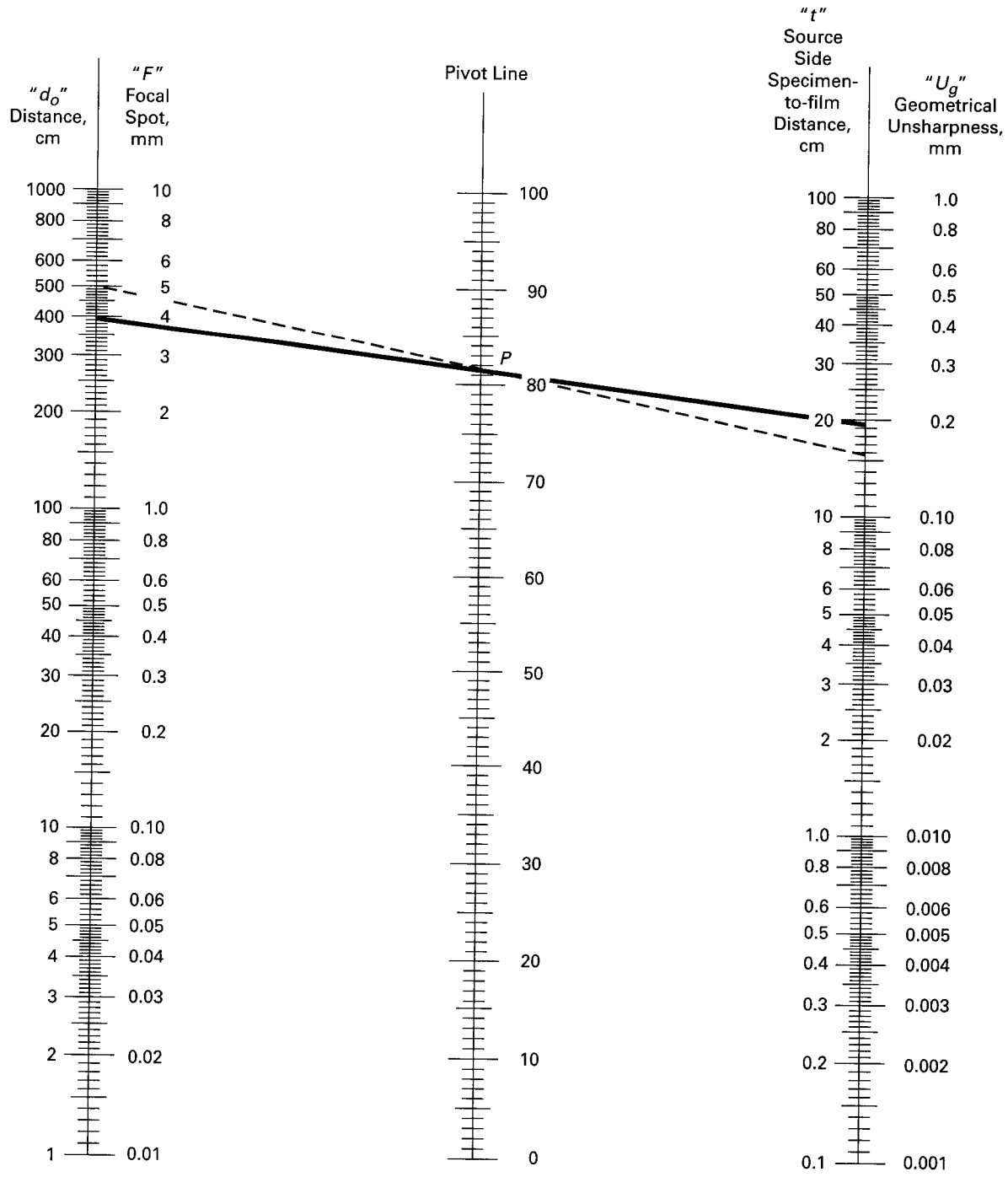


FIG. 4 NOMOGRAM FOR DETERMINING GEOMETRICAL UNSHARPNESS
(Metric Units)

geometric unsharpness (Ug) equation in 15.1 is for information and guidance and provides a means for determining geometric unsharpness values. The amount or degree of unsharpness should be minimized when establishing the radiographic technique.

16. Exposure Calculations or Charts

16.1 Development or procurement of an exposure chart or calculator is the responsibility of the individual laboratory.

16.2 The essential elements of an exposure chart or calculator must relate the following:

16.2.1 Source or machine,

16.2.2 Material type,

16.2.3 Material thickness,

16.2.4 Film type (relative speed),

16.2.5 Film density (see Note 5),

16.2.6 Source or source to film distance,

16.2.7 Kilovoltage or isotope type,

NOTE 5 — For detailed information of film density and density measurement calibration, see Practice E 1079.

16.2.8 Screen type and thickness,

16.2.9 Curies or milliamperes/minutes,

16.2.10 Time of exposure,

16.2.11 Filter (in the primary beam),

16.2.12 Time–temperature development for hand processing; access time for automatic processing; time–temperature development for dry processing, and

16.2.13 Processing chemistry brand name, if applicable.

16.3 The essential elements listed in 16.2 will be accurate for isotopes of the same type, but will vary with X-ray equipment of the same kilovoltage and milliampere rating.

16.4 Exposure charts should be developed for each X-ray machine and corrected each time a major component is replaced, such as the X-ray tube or high-voltage transformer.

16.5 The exposure chart should be corrected when the processing chemicals are changed to a different manufacturer's brand or the time–temperature relationship of the processor may be adjusted to suit the exposure chart. The exposure chart, when using a dry processing method, should be corrected based upon the time–temperature changes of the processor.

17. Technique File

17.1 It is recommended that a radiographic technique log or record containing the essential elements be maintained.

17.2 The radiographic technique log or record should contain the following:

17.2.1 Description, photo, or sketch of the test object illustrating marker layout, source placement, and film location.

17.2.2 Material type and thickness,

17.2.3 Source to film distance,

17.2.4 Film type,

17.2.5 Film density (see Note 5),

17.2.6 Screen type and thickness,

17.2.7 Isotope or X-ray machine identification,

17.2.8 Curie or milliampere minutes,

17.2.9 IQI and shim thickness,

17.2.10 Special masking or filters

17.2.11 Collimator or field limitation device,

17.2.12 Processing method, and

17.2.13 View or location.

17.3 The recommendations of 17.2 are not mandatory, but are essential in reducing the overall cost of radiography, and serve as a communication link between the radiographic interpreter and the radiographic operator.

18. Penetrameters (Image Quality Indicators)

18.1 Practices E 747, E 801, E 1025, and E 1742 should be consulted for detailed information on the design, manufacture and material grouping of IQIs. Practice E 801 addresses IQIs for examination of electronic devices and provides additional details for positioning IQIs, number of IQIs required, and so forth.

18.2 Test Methods E 746 and E 1735 should be consulted for detailed information regarding IQIs which are used for determining relative image quality response of industrial film. The IQIs can also be used for measuring the image quality of the radiographic system or any component of the systems equivalent pentrameter sensitivity (EPS) performance.

18.2.1 An example for determining an EPS performance evaluation of several X-ray machines is as follows:

18.2.1.1 Keep the film and film processing parameters constant, and take multiple image quality exposures with all machines being evaluated. The

machines should be set for a prescribed exposure as stated in the standard and the film density equalized. By comparison of the resultant films, the relative EPS variations between the machines can be determined.

18.2.2 Exposure condition variables may also be studied using this plaque.

18.2.3 While Test Method E 746 plaque can be useful in quantifying relative radiographic image quality, these other applications of the plaque may be useful.

19. Identification of and Location Markers on Radiographs

19.1 *Identification of Radiographs:*

19.1.1 Each radiograph must be identified uniquely so that there is a permanent correlation between the part radiographed and the film. The type of identification and method by which identification is achieved shall be as agreed upon between the customer and inspector.

19.1.2 The minimum identification should at least include the following: the radiographic facility's identification and name, the date, part number and serial number, if used, for unmistakable identification of radiographs with the specimen. The letter *R* should be used to designate a radiograph of a repair area, and may include -1 , -2, etc., for the number of repair.

19.2 *Location Markers:*

19.2.1 Location markers (that is, lead or high-atomic number metals or letters that are to appear as images on the radiographic film) should be placed on the part being examined, whenever practical, and not on the cassette. Their exact locations should also be marked on the surface of the part being radiographed, thus permitting the area of interest to be located accurately on the part, and they should remain on the part during radiographic inspection. Their exact location may be permanently marked in accordance with the customer's requirements.

19.2.2 Location markers are also used in assisting the radiographic interpreter in marking off defective areas of components, castings, or defects in weldments; also, sorting good and rejectable items when more than one item is radiographed on the same film.

19.2.3 Sufficient markers must be used to provide evidence on the radiograph that the required coverage of the object being examined has been obtained, and that overlap is evident, especially during radiography of weldments and castings.

19.2.4 Parts that must be identified permanently may have the serial numbers or section numbers, or both, stamped or written upon them with a marking pen with a special indelible ink, engraved, die stamped, or etched. In any case, the part should be marked in an area not to be removed in subsequent fabrication. If die stamps are used, caution is required to prevent breakage or future fatigue failure. The lowest stressed surface of the part should be used for this stamping. Where marking or stamping of the part is not permitted for some reason, a marked reference drawing or shooting sketch is recommended.

20. Storage of Film

20.1 Unexposed films should be stored in such a manner that they are protected from the effects of light, pressure, excessive heat, excessive humidity, damaging fumes or vapors, or penetrating radiation. Film manufacturers should be consulted for detailed recommendations on film storage. Storage of film should be on a "first in," "first out" basis.

20.2 More detailed information on film storage is provided in Guide E 1254.

21. Safelight Test

21.1 Films should be handled under safelight conditions in accordance with the film manufacturer's recommendations. ANSI PH2.22 can be used to determine the adequacy of safelight conditions in a darkroom.

22. Cleanliness and Film Handling

22.1 Cleanliness is one of the most important requirements for good radiography. Cassettes and screens must be kept clean, not only because dirt retained may cause exposure or processing artifacts in the radiographs, but because such dirt may also be transferred to the loading bench, and subsequently to other film or screens.

22.2 The surface of the loading bench must be kept clean. Where manual processing is used, cleanliness will be promoted by arranging the darkroom with processing facilities on one side and film-handling facilities on the other. The darkroom will then have a wet side and a dry side and the chance of chemical contamination of the loading bench will be relatively slight.

22.3 Films should be handled only at their edges, and with dry, clean hands to avoid finger marks on film surfaces.

22.4 Sharp bending, excessive pressure, and rough handling of any kind must be avoided.

23. Film Processing, General

23.1 To produce a satisfactory radiograph, the care used in making the exposure *must* be followed by equal care in processing. The most careful radiographic techniques can be nullified by incorrect or improper darkroom procedures.

23.2 Sections 24-26 provide general information for film processing. Detailed information on film processing is provided in Guide E 999.

24. Automatic Processing

24.1 *Automatic Processing* — The essence of the automatic processing system is control. The processor maintains the chemical solutions at the proper temperature, agitates and replenishes the solutions automatically, and transports the films mechanically at a carefully controlled speed throughout the processing cycle. Film characteristics must be compatible with processing conditions. It is, therefore, essential that the recommendations of the film, processor, and chemical manufacturers be followed.

24.2 *Automatic Processing, Dry* — The essence of dry automatic processing is the precise control of development time and temperature which results in reproducibility of radiographic density. Film characteristics must be compatible with processing conditions. It is, therefore, essential that the recommendations of the film and processor manufacturers be followed.

25. Manual Processing

25.1 Film and chemical manufacturers should be consulted for detailed recommendations on manual film processing. This section outlines the steps for one acceptable method of manual processing.

25.2 *Preparation* — No more film should be processed than can be accommodated with a minimum separation of ½ in. (12.7 mm). Hangers are loaded and solutions stirred before starting development.

25.3 *Start of Development* — Start the timer and place the films into the developer tank. Separate to a minimum distance of ½ in. (12.7 mm) and agitate in two directions for about 15 s.

25.4 *Development* — Normal development is 5 to 8 min at 68°F (20°C). Longer development time generally yields faster film speed and slightly more contrast. The manufacturer's recommendation should be followed in choosing a development time. When the temperature is higher or lower, development time must be changed. Again, consult manufacturer-recommended development time versus temperature charts. Other recommendations of the manufacturer to be followed are replenishment rates, renewal of solutions, and other specific instructions.

25.5 *Agitation* — Shake the film horizontally and vertically, ideally for a few seconds each minute during development. This will help film develop evenly.

25.6 *Stop Bath or Rinse* — After development is complete, the activity of developer remaining in the emulsion should be neutralized by an acid stop bath or, if this is not possible, by rinsing with vigorous agitation in clear water. Follow the film manufacturer's recommendation of stop bath composition (or length of alternative rinse), time immersed, and life of bath.

25.7 *Fixing* — The films must not touch one another in the fixer. Agitate the hangers vertically for about 10 s and again at the end of the first minute, to ensure uniform and rapid fixation. Keep them in the fixer until fixation is complete (that is, at least twice the clearing time), but not more than 15 min in relatively fresh fixer. Frequent agitation will shorten the time of fixation.

25.8 *Fixer Neutralizing* — The use of a hypo eliminator or fixer neutralizer between fixation and washing may be advantageous. These materials permit a reduction of both time and amount of water necessary for adequate washing. The recommendations of the manufacturers as to preparation, use, and useful life of the baths should be observed rigorously.

25.9 *Washing* — The washing efficiency is a function of wash water, its temperature, and flow, and the film being washed. Generally, washing is very slow below 60°F (16°C). When washing at temperatures above 85°F (30°C), care should be exercised not to leave films in the water too long. The films should be washed in batches without contamination from new film brought over from the fixer. If pressed for capacity, as more films are put in the wash, partially washed film should be moved in the direction of the inlet.

25.9.1 The cascade method of washing uses less water and gives better washing for the same length of time. Divide the wash tank into two sections (may be two tanks). Put the films from the fixer in the outlet section. After partial washing, move the batch of film to the inlet section. This completes the wash in fresh water.

25.9.2 For specific washing recommendations, consult the film manufacturer.

25.10 *Wetting Agent* — Dip the film for approximately 30 s in a wetting agent. This makes water drain evenly off film, which facilitates quick, even drying.

25.11 *Residual Fixer Concentrations* — If the fixing chemicals are not removed adequately from the film, they

will in time cause staining or fading of the developed image. Residual fixer concentrations permissible depend upon whether the films are to be kept for commercial purposes (3 to 10 years) or must be of archival quality. Archival quality processing is desirable for all radiographs whenever average relative humidity and temperature are likely to be excessive, as is the case in tropical and subtropical climates. The method of determining residual fixer concentrations may be ascertained by reference to ANSI PH4.8, PH1.28, and PH1.41.

25.12 *Drying* — Drying is a function of (*1*) film (base and emulsion); (*2*) processing (hardness of emulsion after washing, use of wetting agent); and (*3*) drying air (temperature, humidity, flow). Manual drying can vary from still air drying at ambient temperature to as high as 140°F (60°C) with air circulated by a fan. Film manufacturers should again be contacted for recommended drying conditions. Take precaution to tighten film on hangers, so that it cannot touch in the dryer. Too hot a drying temperature at low humidity can result in uneven drying and should be avoided.

26. Testing Developer

26.1 It is desirable to monitor the activity of the radiographic developing solution. This can be done by periodic development of film strips exposed under carefully controlled conditions, to a graded series of radiation intensities or time, or by using a commercially available strip carefully controlled for film speed and latent image fading.

27. Viewing Radiographs

27.1 Guide E 1390 provides detailed information on requirements for illuminators. The following sections provide general information to be considered for use of illuminators.

27.2 *Transmission* — The illuminator must provide light of an intensity that will illuminate the average density areas of the radiographs without glare and it must diffuse the light evenly over the viewing area. Commercial fluorescent illuminators are satisfactory for radiographs of moderate density; however, high light intensity illuminators are available for densities up to 3.5 or 4.0. Masks should be available to exclude any extraneous light from the eyes of the viewer when viewing radiographs smaller than the viewing port or to cover low-density areas.

27.3 *Reflection* — Radiographs on a translucent or opaque backing may be viewed by reflected light. It is recommended that the radiograph be viewed under diffuse lighting conditions to prevent excess glare. Optical magnification can be used in certain instances to enhance the interpretation of the image.

28. Viewing Room

28.1 Subdued lighting, rather than total darkness, is preferable in the viewing room. The brightness of the surroundings should be about the same as the area of interest in the radiograph. Room illumination must be so arranged that there are no reflections from the surface of the film under examination.

29. Storage of Processed Radiographs

29.1 Guide E 1254 provides detailed information on controls and maintenance for storage of radiographs and unexposed film. The following sections provide general information for storage of radiographs.

29.2 Envelopes having an edge seam, rather than a center seam, and joined with a nonhygroscopic adhesive, are preferred, since occasional staining and fading of the image is caused by certain adhesives used in the manufacture of envelopes (see ANSI PH1.53).

30. Records

30.1 It is recommended that an inspection log (a log may consist of a card file, punched card system, a book, or other record) constituting a record of each job performed, be maintained. This record should comprise, initially, a job number (which should appear also on the films), the identification of the parts, material or area radiographed, the date the films are exposed, and a complete record of the radiographic procedure, in sufficient detail so that any radiographic techniques may be duplicated readily. If calibration data, or other records such as card files or procedures, are used to determine the procedure, the log need refer only to the appropriate data or other record. Subsequently, the interpreter's findings and disposition (acceptance or rejection), if any, and his initials, should be entered for each job.

31. Reports

31.1 When written reports of radiographic examinations are required, they should include the following, plus such other items as may be agreed upon:

31.1.1 Identification of parts, material, or area.

31.1.2 Radiographic job number.

31.1.3 Findings and disposition, if any. This information can be obtained directly from the log.

32. Identification of Completed Work

32.1 Whenever radiography is an inspective (rather than investigative) operation whereby material is accepted or rejected, all parts and material that have been accepted should be marked permanently, if possible, with a characteristic identifying symbol which will indicate to subsequent or final examiners the fact of radiographic acceptance.

32.2 Whenever possible, the completed radiographs should be kept on file for reference. The custody of radiographs and the length of time they are preserved should be agreed upon between the contracting parties.

33. Keywords

33.1 exposure calculations; film system; gamma-ray; image quality indicator (IQI); radiograph; radiographic examination; radiographic quality level; technique file; X-ray

APPENDIX
(Nonmandatory Information)

X1. USE OF FLUORESCENT SCREENS

X1.1 *Description* — Fluorescent intensifying screens have a cardboard or plastic support coated with a uniform layer of inorganic phosphor (crystalline substance). The support and phosphor are held together by a radiotransparent binding material. Fluorescent screens derive their name from the fact that their phosphor crystals "fluoresce" (emit visible light) when struck by X or gamma radiation. Some phosphors like calcium tungstate ($CaWO_4$) give off blue light while others known as rare earth emit light green.

X1.2 *Purpose and Film Types* — Fluorescent screen exposures are usually much shorter than those made without screens or with lead intensifying screens, because radiographic films generally are more responsive to visible light than to direct X-radiation, gamma radiation, and electrons.

X1.2.1 Films fall into one of two categories: nonscreen type film having moderate light response, and screen type film specifically sensitized to have a very high blue or green light response. Fluorescent screens can reduce conventional exposures by as much as 150 times, depending on film type.

X1.3 *Image Quality and Use* — The image quality associated with fluorescent screen exposures is a function of sharpness, mottle, and contrast. Screen sharpness depends on phosphor crystal size, thickness of the crystal layer, and the reflective base coating. Each crystal emits light relative to its size and in all directions thus producing a relative degree of image unsharpness. To minimize this unsharpness, screen to film contact should be as intimate as possible. Mottle adversely affects image quality in two ways. First, a "quantum" mottle is dependent upon the amount of X or gamma radiation actually absorbed by the fluorescent screen, that is, faster screen/film systems lead to greater mottle and poorer image quality. A "structural" mottle, which is a function of crystal size, crystal uniformity, and layer thickness, is minimized by using screens having small, evenly spaced crystals in a thin crystalline layer. Fluorescent screens are highly sensitive to longer wavelength scattered radiation. Consequently, to maximize contrast when this non-image forming radiation is excessive, fluorometallic intensifying screens or fluorescent screens backed by lead screens of appropriate thickness are recommended. Screen technology has seen significant advances in recent years, and today's fluorescent screens have smaller crystal size, more uniform crystal packing, and reduced phosphor thickness. This translates into greater screen/film speed with reduced unsharpness and mottle. These improvements can represent some meaningful benefits for industrial radiography, as indicated by the three examples as follows:

X1.3.1 *Reduced Exposure (Increased Productivity)* — There are instances where prohibitively long exposure times make conventional radiography impractical. An example is the inspection of thick, high atomic number materials with low curie isotopes. Depending on many variables, exposure time may be reduced by factors ranging from 2× to 105× when the appropriate fluorescent screen/film combination is used.

X1.3.2 *Improved Safety Conditions (Field Sites)* — Because fluorescent screens provide reduced exposure, the length of time that non-radiation workers must evacuate a radiographic inspection site can be reduced significantly.

X1.3.3 *Extended Equipment Capability* — Utilizing the speed advantage of fluorescent screens by translating it into reduced energy level. An example is that a 150 kV X-ray tube may do the job of a 300 kV tube, or that iridium 192 may be used in applications normally requiring cobalt 60. It is possible for overall image quality to be better at the lower kV with fluorescent screens than at a higher energy level using lead screens.

STANDARD PRACTICE FOR DESIGN, MANUFACTURE, AND MATERIAL GROUPING CLASSIFICATION OF WIRE IMAGE QUALITY INDICATORS (IQI) USED FOR RADIOLOGY

SE-747

(Identical with ASTM Specification E 747-97)

1. Scope

1.1 This practice covers the design, material grouping classification, and manufacture of wire image quality indicators (IQI) used to indicate the quality of radiologic images.

1.2 This practice is applicable to X-ray and gamma-ray radiology.

1.3 This practice covers the use of wire penetrameters as the controlling image quality indicator for the material thickness range from 6.4 to 152 mm (0.25 to 6.0 in.).

1.4 The values stated in inch-pound units are to be regarded as standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 139 Specification for Phosphor Bronze Rod, Bar, and Shapes

B 150 Specification for Aluminum Bronze Rod, Bar, and Shapes

B 161 Specification for Nickel Seamless Pipe and Tube

B 164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire

B 166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, and N06690) and Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) Rod, Bar, and Wire

E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiography

E 1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions* — The definitions of terms in Terminology E 1316, Section D, relating to gamma and X-radiology, shall apply to the terms used in this practice.

4. Wire IQI Requirements

4.1 The quality of all levels of examination shall be determined by a set of wires conforming to the following requirements:

4.1.1 Wires shall be fabricated from materials or alloys identified or listed in accordance with 7.2. Other materials may be used in accordance with 7.3.

4.1.2 The IQI consists of sets of wires arranged in order of increasing diameter. The diameter sizes specified in Table 1 are established from a consecutive series of numbers taken in general from the ISO/R 10 series. The IQI shall be fabricated in accordance with the requirements specified in Figs. 1 through 8 and Tables 1, 2, and 3. IQIs previously manufactured to the requirements of Annex A1 may be used as an alternate provided all other requirements of this practice are met.

TABLE 1
WIRE IQI SIZES AND WIRE IDENTITY NUMBERS

SET A		SET B	
Wire Diameter, in. (mm)	Wire Identity	Wire Diameter, in. (mm)	Wire Identity
0.0032 (0.08)[A]	1	0.010 (0.25)	6
0.004 (0.1)	2	0.013 (0.33)	7
0.005 (0.13)	3	0.016 (0.4)	8
0.0063 (0.16)	4	0.020 (0.51)	9
0.008 (0.2)	5	0.025 (0.64)	10
0.010 (0.25)	6	0.032 (0.81)	11
SET C		**SET D**	
Wire Diameter, in. (mm)	Wire Identity	Wire Diameter, in. (mm)	Wire Identity
0.032 (0.81)	11	0.10 (2.5)	16
0.040 (1.02)	12	0.126 (3.2)	17
0.050 (1.27)	13	0.160 (4.06)	18
0.063 (1.6)	14	0.20 (5.1)	19
0.080 (2.03)	15	0.25 (6.4)	20
0.100 (2.5)	16	0.32 (8)	21

[A]The 0.0032 wire may be used to establish a special quality level as agreed upon between the purchaser and the supplier.

TABLE 2
WIRE DIAMETER TOLERANCES (mm)

Wire Diameter (d), mm	Tolerance, mm
$0.000 < d \leq 0.125$	±0.0025
$0.125 < d \leq 0.25$	±0.005
$0.25 < d \leq 0.5$	±0.01
$0.50 < d \leq 1.6$	±0.02
$1.6 < d \leq 4$	±0.03
$4.0 < d \leq 8$	±0.05

TABLE 3
WIRE DIAMETER TOLERANCES (in.)

Wire Diameter (d), in	Tolerance, in
$0.000 < d \leq 0.005$	±0.0001
$0.005 < d \leq 0.010$	±0.0002
$0.010 < d \leq 0.020$	±0.0004
$0.020 < d \leq 0.063$	±0.0008
$0.063 < d \leq 0.160$	±0.0012
$0.160 < d \leq 0.320$	±0.0020

4.1.3 Image quality indicator (IQI) designs other than those shown in Figs. 1 through 8 and Annex A1 are permitted by contractual agreement. If an IQI set as listed in Table 1 or Annex A1 is modified in size, it must contain the grade number, set identity, and essential wire. It must also contain two additional wires that are the next size larger and the next size smaller as specified in the applicable set listed in Table 1.

4.1.4 Each set must be identified using letters and numbers made of industrial grade lead or of a material of similar radiographic density. Identification shall be as shown in Figs. 1 through 8 or Annex A1, unless otherwise specified by contractual agreement.

5. Image Quality Indicator (IQI) Procurement

5.1 When selecting IQIs for procurement, the following factors should be considered:

5.1.1 Determine the alloy group(s) of the material to be examined.

5.1.2 Determine the thickness or thickness range of the material(s) to be examined.

5.1.3 Select the applicable IQIs that represent the required IQI thickness(s) and alloy(s).

6. Image Quality Levels

6.1 The quality level required using wire penetrameters shall be equivalent to the 2-2T level of Practice E 1025 for hole-type IQIs unless a higher or lower quality level is agreed upon between purchaser and supplier. Table 4 provides a list of various hole-type IQIs and the diameter of wires of corresponding equivalent penetrameter sensitivity (EPS) with the applicable 1T, 2T, and 4T holes in the IQI. This table can be used for determining 1T, 2T, and 4T quality levels. Appendix X1 gives the equation for calculating other equivalencies if needed.

6.2 In specifying quality levels, the contract, purchase order, product specification, or drawing should clearly indicate the thickness of material to which the quality level applies. Careful consideration of required quality levels is particularly important.

7. Material Groups

7.1 *General:*

7.1.1 Materials have been designated in eight groups based on their radiographic absorption characteristics: groups 03, 02, and 01 for light metals and groups 1 through 5 for heavy metals.

7.1.2 The light metal groups, magnesium (Mg), aluminum (Al), and titanium (Ti), are identified 03, 02, and 01 respectively, for their predominant alloying constituent. The materials are listed in order of increasing radiation absorption.

7.1.3 The heavy metal groups, steel, copper-base, nickel-base, and kindred alloys, are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

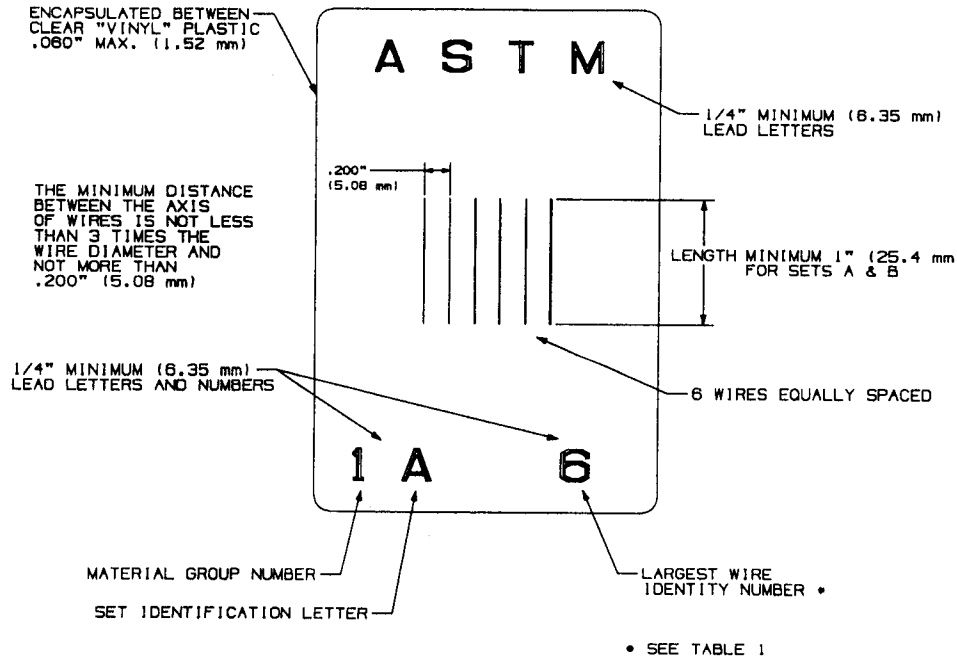


FIG. 1 SET A/ALTERNATE 1

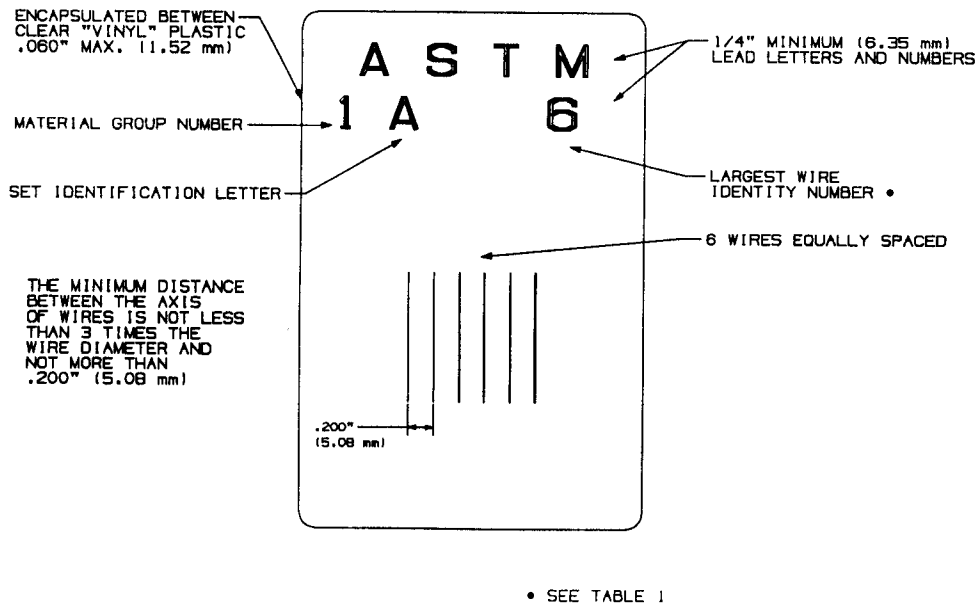


FIG. 2 SET A/ALTERNATE 2

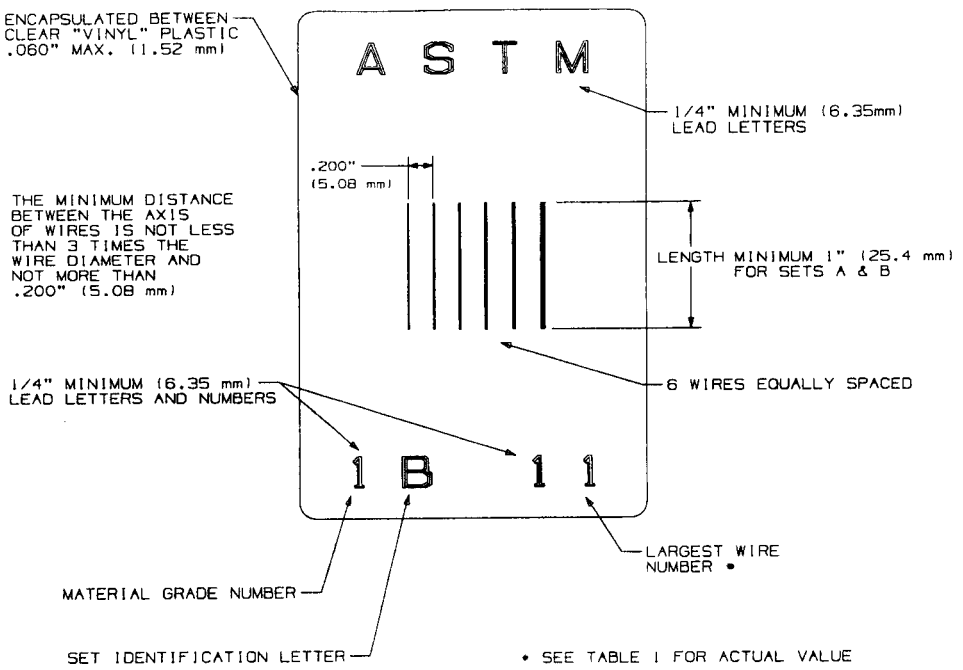


FIG. 3 SET B/ALTERNATE 1

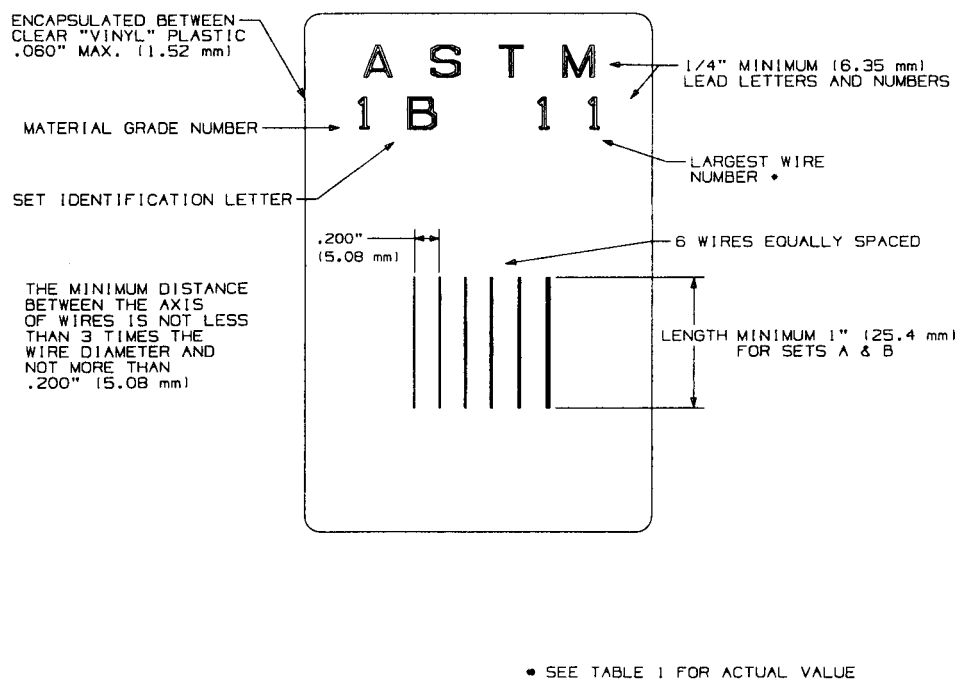


FIG. 4 SET B/ALTERNATE 2

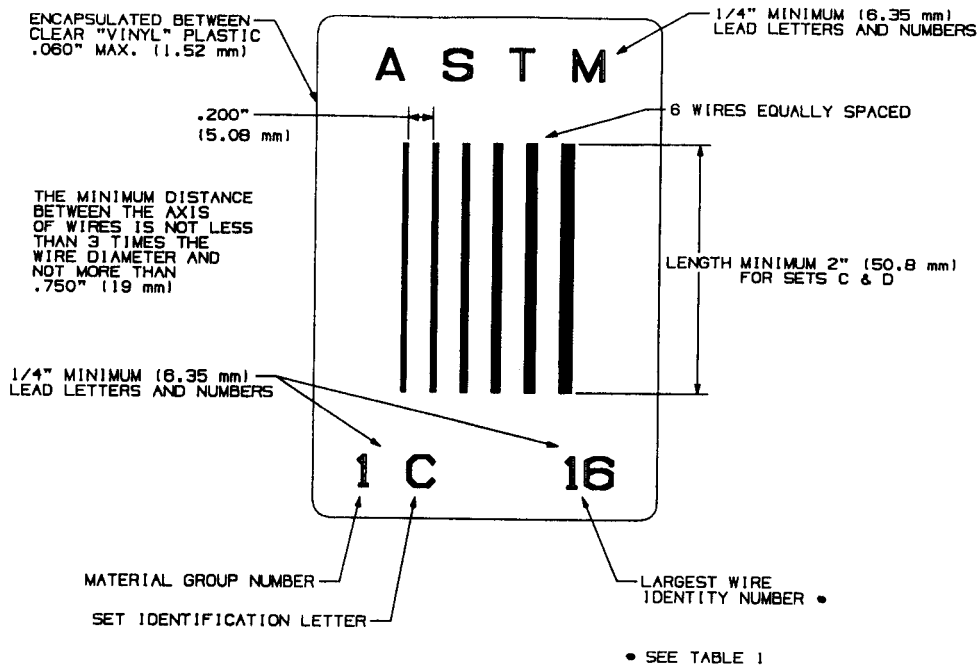


FIG. 5 SET C/ALTERNATE 1

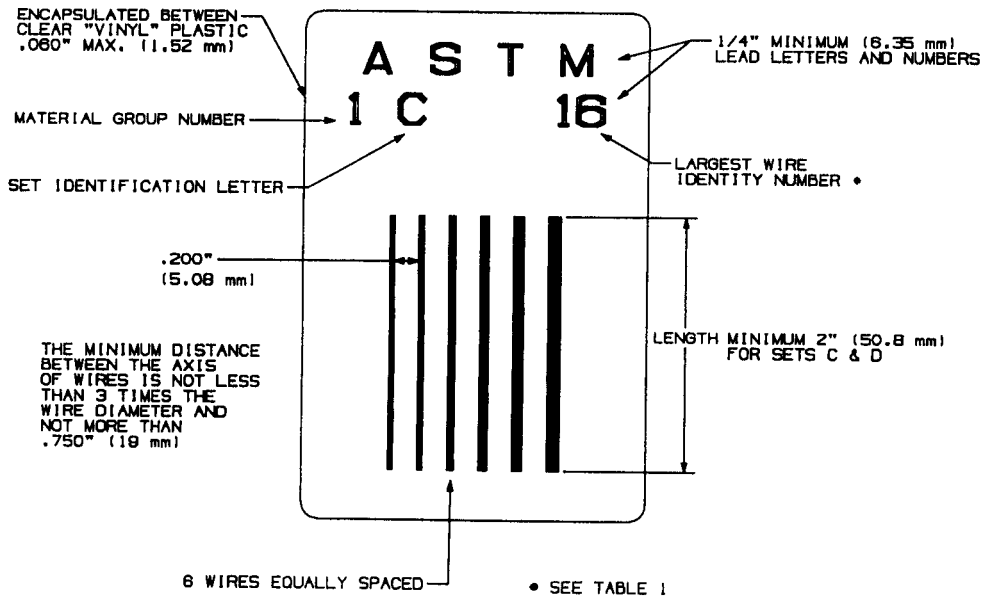


FIG. 6 SET C/ALTERNATE 2

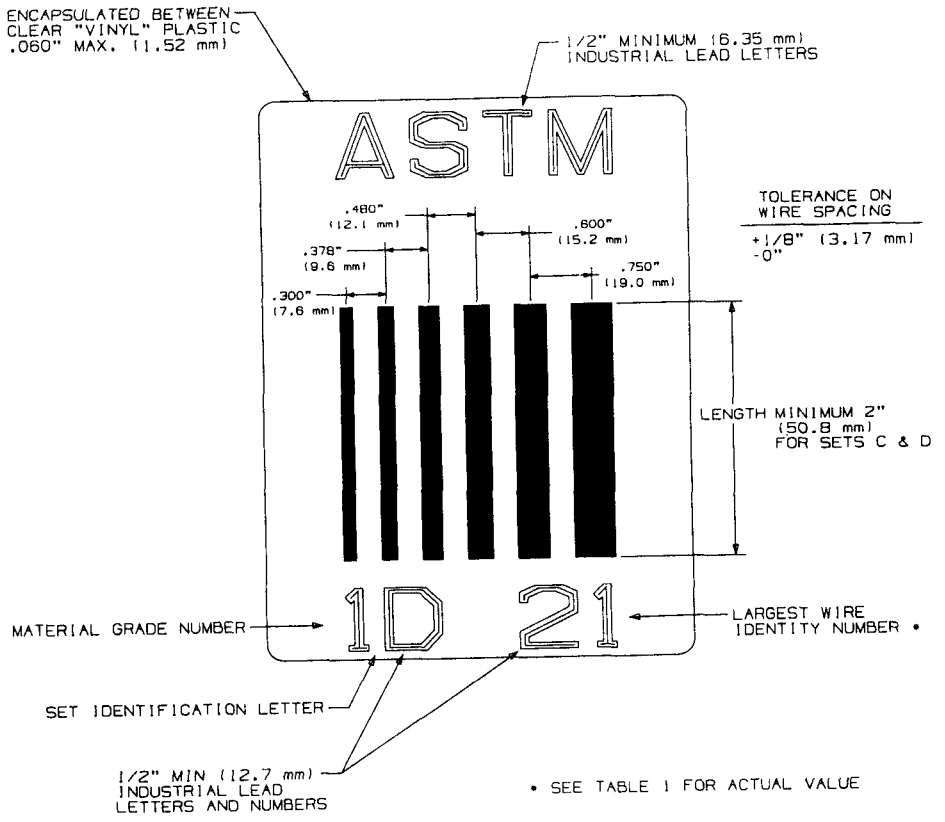


FIG. 7 SET D/ALTERNATE 1

7.1.4 Common trade names or alloy designations have been used for clarification of the pertinent materials.

7.1.5 The materials from which the IQI for the group are to be made are designated in each case and these IQIs are applicable for all materials listed in that group. In addition, any group IQI may be used for any material with a higher group number, provided the applicable quality level is maintained.

7.2 *Materials Groups:*

7.2.1 *Materials Group 01:*

7.2.1.1 Image quality indicators (IQIs) shall be made of titanium or titanium shall be the predominant alloying constituent.

7.2.1.2 Use on all alloys of which titanium is the predominant alloying constituent.

7.2.2 *Materials Group 02:*

7.2.2.1 Image quality indicators (IQIs) shall be made of aluminum or aluminum shall be the predominant alloying constituent.

7.2.2.2 Use on all alloys of which aluminum is the predominant alloying constituent.

7.2.3 *Materials Group 03:*

7.2.3.1 Image quality indicators (IQIs) shall be made of magnesium or magnesium shall be the predominant alloying constituent.

7.2.3.2 Use on all alloys of which magnesium is the predominant alloying constituent.

7.2.4 *Materials Group 1:*

7.2.4.1 Image quality indicators (IQIs) shall be made of carbon steel or Type 300 series stainless steel.

7.2.4.2 Use on all carbon steel, low-alloy steels, stainless steels, and manganese-nickel-aluminum bronze (Superston).

7.2.5 *Materials Group 2:*

7.2.5.1 Image quality indicators (IQIs) shall be made of aluminum bronze (Alloy No. 623 of Specification B 150) or equivalent, or nickel-aluminum bronze (Alloy No. 630 of Specification B 150) or equivalent.

7.2.5.2 Use on all aluminum bronzes and all nickel-aluminum bronzes.

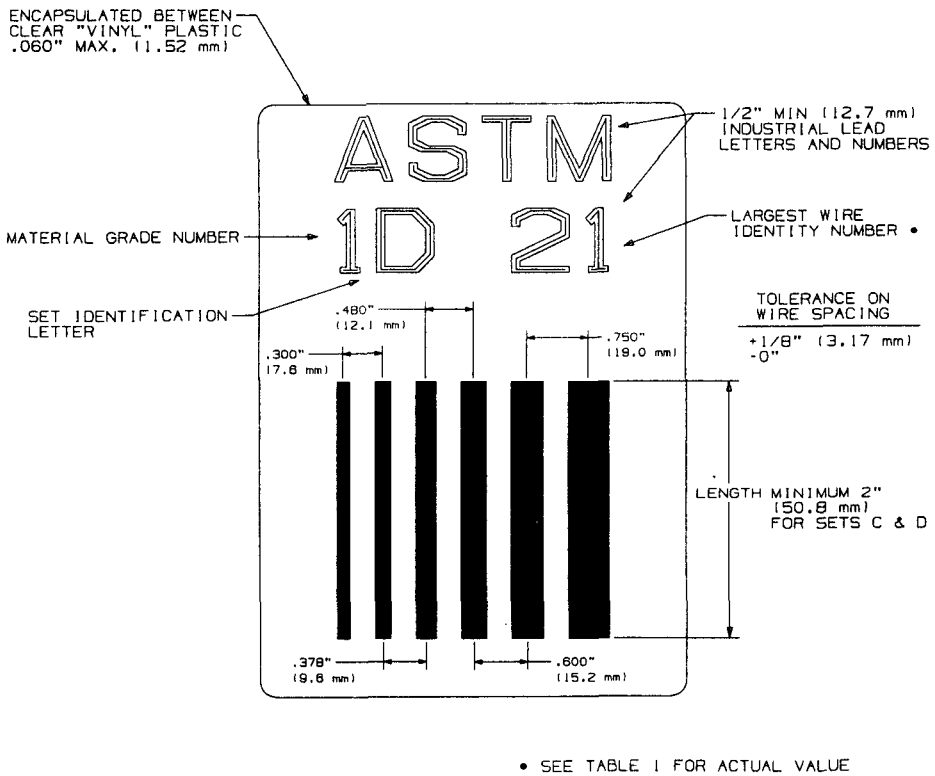


FIG. 8 SET D/ALTERNATE 2

7.2.6 *Materials Group 3:*

7.2.6.1 Image quality indicators (IQIs) shall be made of nickel-chromium-iron alloy (UNS No. N06600) (Inconel). (See Specification B 166.)

7.2.6.2 Use on nickel-chromium-iron alloy and 18% nickel-maraging steel.

7.2.7 *Materials Group 4:*

7.2.7.1 Image quality indicators (IQIs) shall be made of 70 to 30 nickel-copper alloy (Monel) (Class A or B of Specification B 164) or equivalent, or 70 to 30 copper-nickel alloy (Alloy G of Specification B 161) or equivalent.

7.2.7.2 Use on nickel, copper, all nickel-copper series, or copper-nickel series of alloys, and all brasses (copper-zinc alloys). Group 4 IQIs may include the leaded brasses since leaded brass increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

7.2.8 *Materials Group 5:*

7.2.8.1 Image quality indicators (IQIs) shall be made of tin bronze (Alloy D of Specification B 139).

7.2.8.2 Use on tin bronzes including gun-metal and valve bronze, or leaded-tin bronze of higher lead content than valve bronze. Group 5 IQIs may include bronze of higher lead content since leaded bronze increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

NOTE 1 — In developing the eight listed materials groups, a number of other trade names or other nominal alloy designations were evaluated. For the purpose of making this practice as useful as possible, these materials are listed and categorized, by group, as follows:

(1) Group 2 — Haynes Alloy IN-100.

(2) Group 3 — Haynes Alloy No. 713C, Hastelloy D, G. E. Alloy SEL, Haynes Stellite Alloy No. 21, GMR-235 Alloy, Haynes Alloy No. 93, Inconel X, Inconel 718, and Haynes Stellite Alloy No. S-816.

(3) Group 4 — Hastelloy Alloy F, Hastelloy Alloy X, and Multimeter Alloy Rene 41.

(4) Group 5 — Alloys in order of increasing attenuation: Hastelloy Alloy B, Hastelloy Alloy C, Haynes Stellite Alloy No. 31, Thetaloy, Haynes Stellite No. 3, Haynes Alloy No. 25. Image quality indicators (IQIs) of any of these materials are considered applicable for the materials that follow it.

NOTE 2 — The committee formulating these recommendations recommends other materials may be added to the materials groups listed as

TABLE 4
WIRE SIZES EQUIVALENT TO CORRESPONDING 1T, 2T, AND 4T HOLES IN VARIOUS HOLE TYPE PLAQUES

Plaque Thickness, in. (mm)	Plaque IQI Identification Number	Diameter of wire with EPS of hole in plaque, in. (mm)		
		1T	2T	4T
0.005 (0.13)	5		0.0038 (0.09)	0.006 (0.15)
0.006 (0.16)	6		0.004 (0.10)	0.0067 (0.18)
0.008 (0.20)	8	0.0032 (0.08)	0.005 (0.13)	0.008 (0.20)
0.009 (0.23)	9	0.0035 (0.09)	0.0056 (0.14)	0.009 (0.23)
0.010 (0.25)	10	0.004 (0.10)	0.006 (0.15)	0.010 (0.25)
0.012 (0.30)	12	0.005 (0.13)	0.008 (0.20)	0.012 (0.28)
0.015 (0.38)	15	0.0065 (0.16)	0.010 (0.25)	0.016 (0.41)
0.017 (0.43)	17	0.0076 (0.19)	0.012 (0.28)	0.020 (0.51)
0.020 (0.51)	20	0.010 (0.25)	0.015 (0.38)	0.025 (0.63)
0.025 (0.64)	25	0.013 (0.33)	0.020 (0.51)	0.032 (0.81)
0.030 (0.76)	30	0.016 (0.41)	0.025 (0.63)	0.040 (1.02)
0.035 (0.89)	35	0.020 (0.51)	0.032 (0.81)	0.050 (1.27)
0.040 (1.02)	40	0.025 (0.63)	0.040 (1.02)	0.063 (1.57)
0.050 (1.27)	50	0.032 (0.81)	0.050 (1.27)	0.080 (2.03)
0.060 (1.52)	60	0.040 (1.02)	0.063 (1.57)	0.100 (2.54)
0.070 (1.78)	70	0.050 (1.27)	0.080 (2.03)	0.126 (3.20)
0.080 (2.03)	80	0.063 (1.57)	0.100 (2.54)	0.160 (4.06)
0.100 (2.5)	100	0.080 (2.03)	0.126 (3.20)	0.200 (5.08)
0.120 (3.05)	120	0.100 (2.54)	0.160 (4.06)	0.250 (6.35)
0.140 (3.56)	140	0.126 (3.20)	0.200 (5.08)	0.320 (8.13)
0.160 (4.06)	160	0.160 (4.06)	0.250 (6.35)	
0.200 (5.08)	200	0.200 (5.08)	0.320 (8.13)	
0.240 (6.10)	240	0.250 (6.35)		
0.280 (7.11)	280	0.320 (8.13)		

the need arises or as more information is gained, or that additional materials groups may be added.

7.3 *Method for Other Materials:*

7.3.1 For materials not herein covered, IQIs of the same materials, or any other material, may be used if the following requirements are met. Two blocks of equal thickness, one of the material to be examined (production material) and one of the IQI material, shall be radiographed on one film by one exposure at the lowest energy level to be used for production. Transmission densitometer measurements of the radiographic image of each material shall be made. The density of each image shall be between 2.0 and 4.0. If the image density of the IQI material is within 1.00 to 1.15 times (−0% to +15%) the image density of the production material, IQIs made of that IQI material may be used in radiography of that production material. The percentage figure is based on the radiographic density of the IQI material.

7.3.2 It shall always be permissible to use IQIs of similar composition as the material being examined.

8. Image Quality Indicator (IQI) Certification

8.1 Documents shall be provided by the IQI manufacturer attesting to the following:

8.1.1 IQI identification alternate, if used.

8.1.2 Material type.

8.1.3 Conformance to specified tolerances for dimensional values.

8.1.4 ASTM standard designation, for example, ASTM E 747 — (year designation) used for manufacturing.

9. Precision and Bias

9.1 *Precision and Bias* — No statement is made about the precision or bias for indicating the quality of images since the results merely state whether there is conformance to the criteria for success specified in this practice.

10. Keywords

10.1 density; image quality level; IQI; radiologic; radiology; X-ray and gamma radiation

ANNEX

(Mandatory Information)

A1. ALTERNATE IQI IDENTIFICATION

A1.1 The use of IQIs with identifications as shown in Figs. A1.1 through A1.9 and as listed in Table A1.1 is permitted as an acceptable alternate provided all other requirements of Practice E 747 are satisfied.

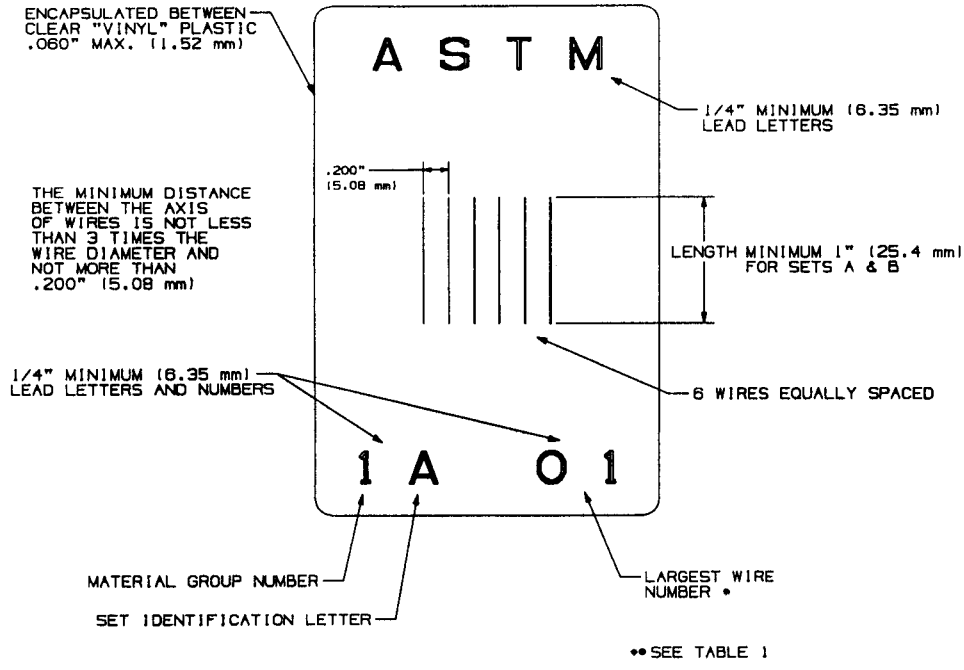


FIG. A1.1 SET A/ALTERNATE 1

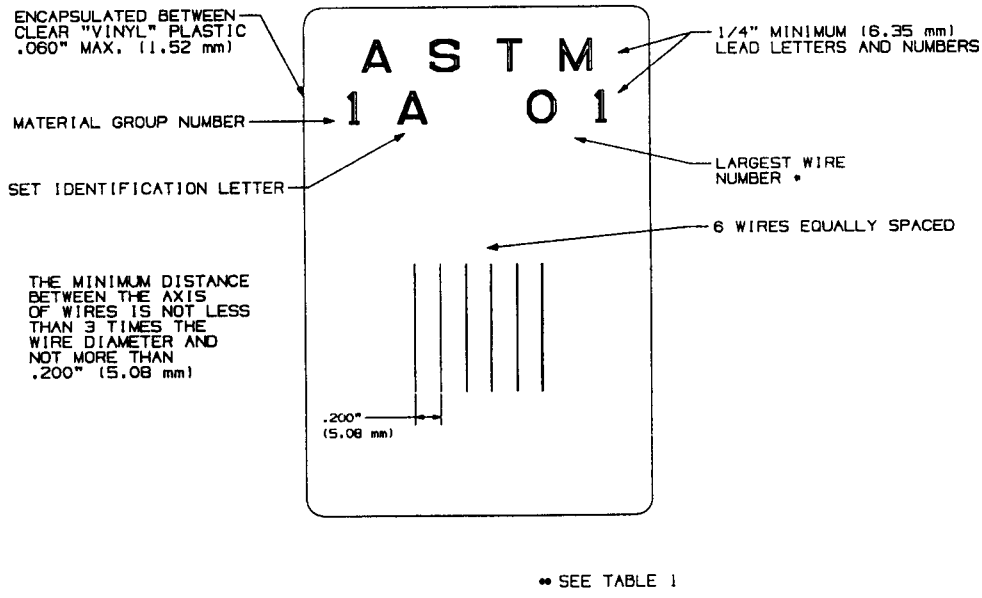


FIG. A1.2 SET A/ALTERNATE 2

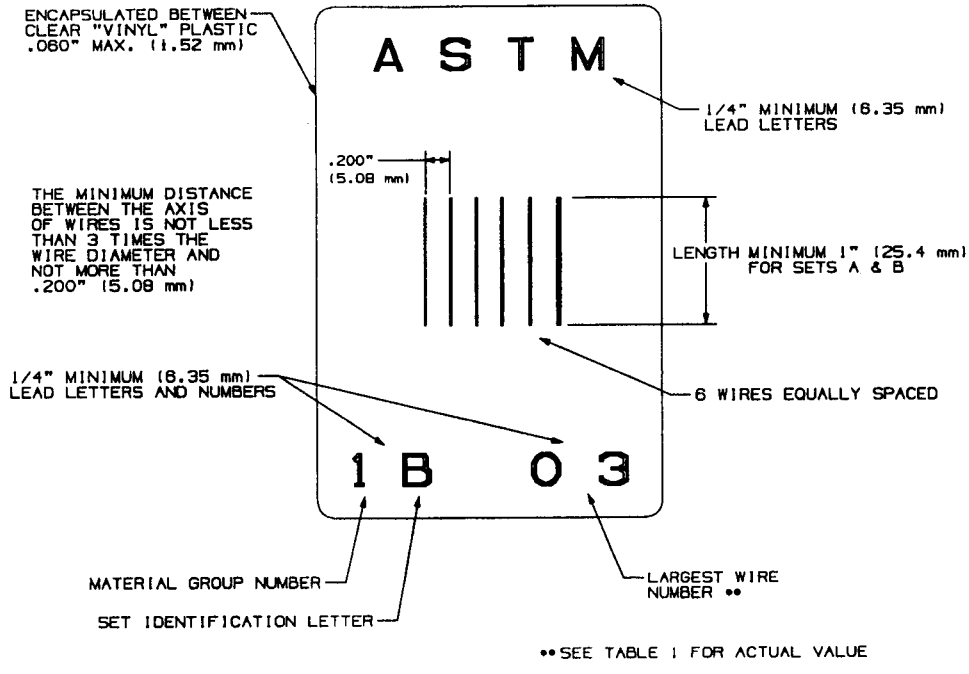


FIG. A1.3 SET B/ALTERNATE 1

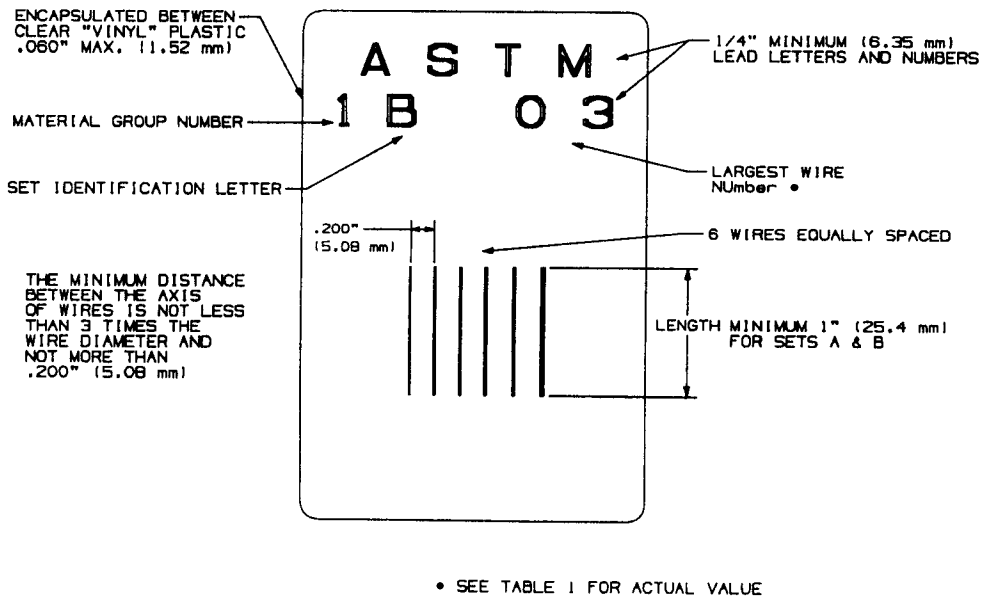


FIG. A1.4 SET B/ALTERNATE 2

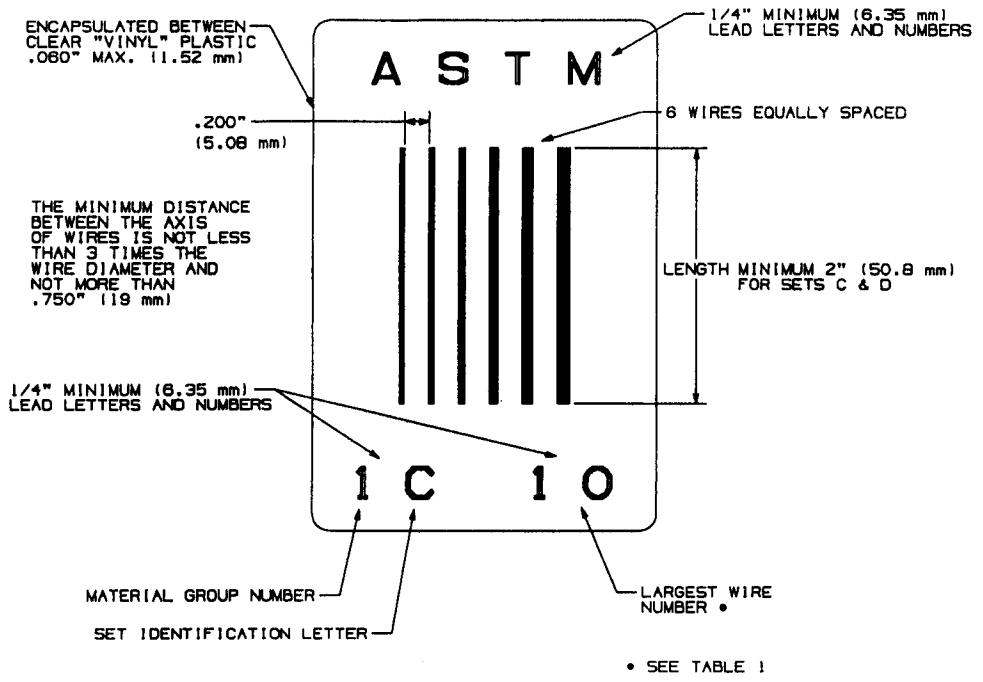


FIG. A1.5 SET C/ALTERNATE 1

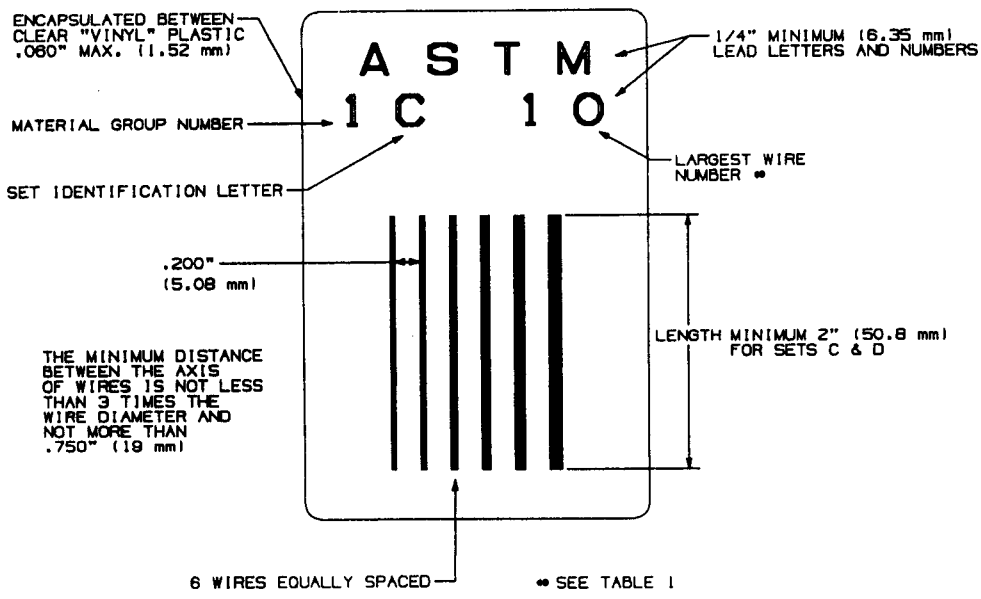


FIG. A1.6 SET C/ALTERNATE 2

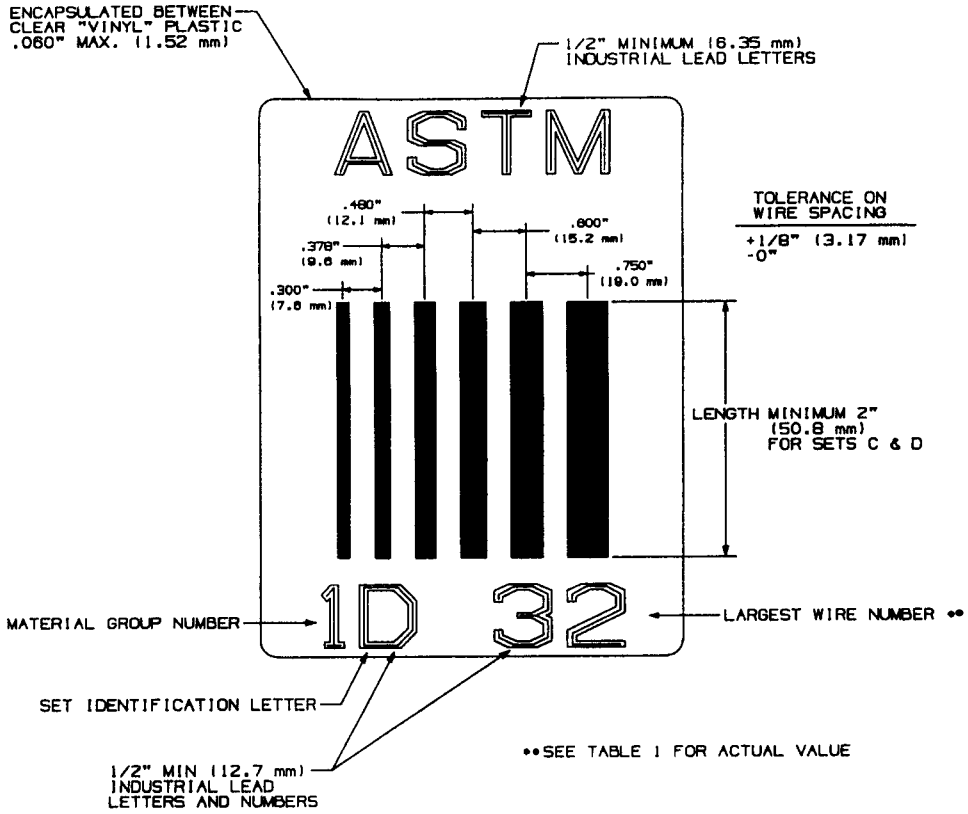


FIG. A1.7 SET D/ALTERNATE 1

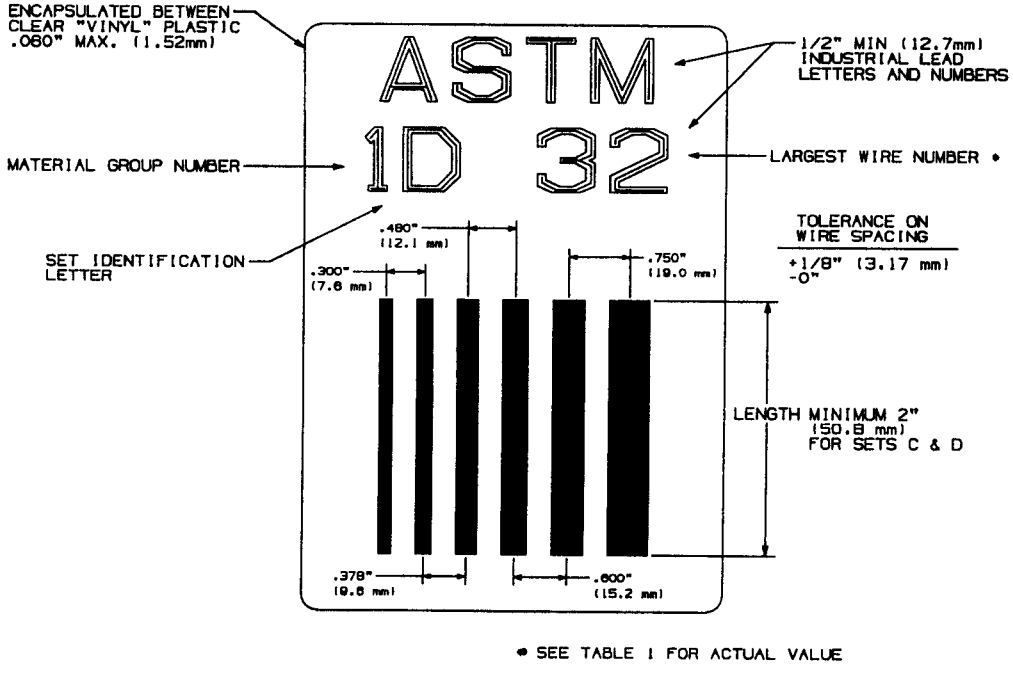
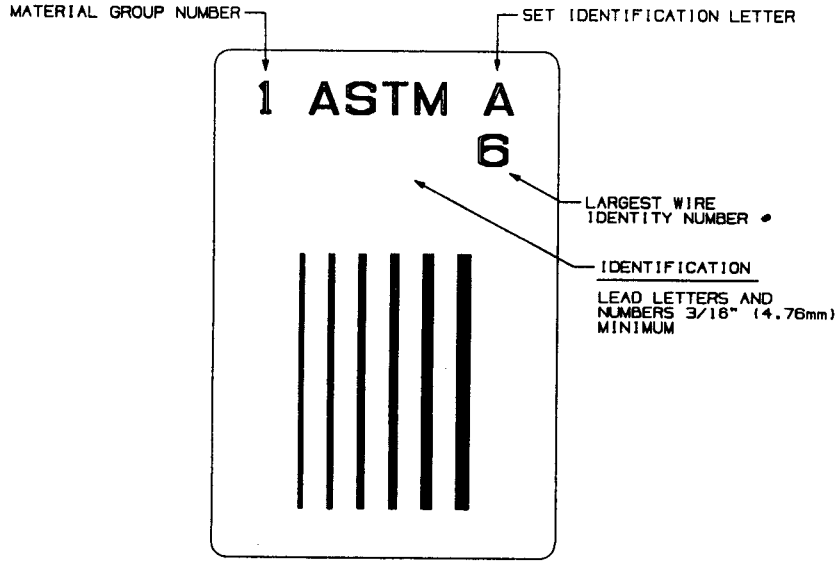


FIG. A1.8 SET D/ALTERNATE 2



NOTE—All other IQI requirements as shown on Figs. 1 through 8 or Figs. A1.1 through A1.8 apply.

FIG. A1.9 ALTERNATE IDENTIFICATION LOCATIONS AND LETTER, NUMBER SIZE-TYPICAL ALL SETS (A, B, C, D)

TABLE A1.1
PENETRAMETER SIZES WIRE DIAMETER, in. (mm)

SET A	SET B
0.0032 (0.08)[A]	0.010 (0.25)
0.004 (0.1)	0.013 (0.33)
0.005 (0.13)	0.016 (0.41)
0.0063 (0.16)	0.020 (0.51)
0.008 (0.2)	0.025 (0.64)
0.010 (0.25)	0.032 (0.81)
SET C	**SET D**
0.032 (0.81)	0.100 (2.5)
0.040 (1.02)	0.126 (3.2)
0.050 (1.27)	0.160 (4.06)
0.063 (1.6)	0.20 (5.1)
0.080 (2.03)	0.25 (6.4)
0.100 (2.5)	0.32 (0.81)

[A] The 0.0032 wire may be used to establish a special quality level as agreed upon between the purchaser and the supplier.

APPENDIX

(Nonmandatory Information)

X1. CALCULATING OTHER EQUIVALENTS

X1.1 The equation to determine the equivalencies between wire and (hole type) IQIs is as follows:

$$F^3d^3l = T^2H^2(\pi/4)$$

where:

F = form factor for wire, 0.79,
d = wire diameter, in. (mm),
l = effective length of wire, 0.3 in. (7.6 mm),
T = plaque thickness, in. (mm), and
H = diameter of hole, in. (mm).

X1.2 It should be noted that the wire and plaque (hole type) IQI sensitivities cannot be related by a fixed constant.

X1.3 Figures X1.1 and X1.2 are conversion charts for hole type IQI's containing 1T and 2T holes to wires. The sensitivities are given as a percentage of the specimen thickness.

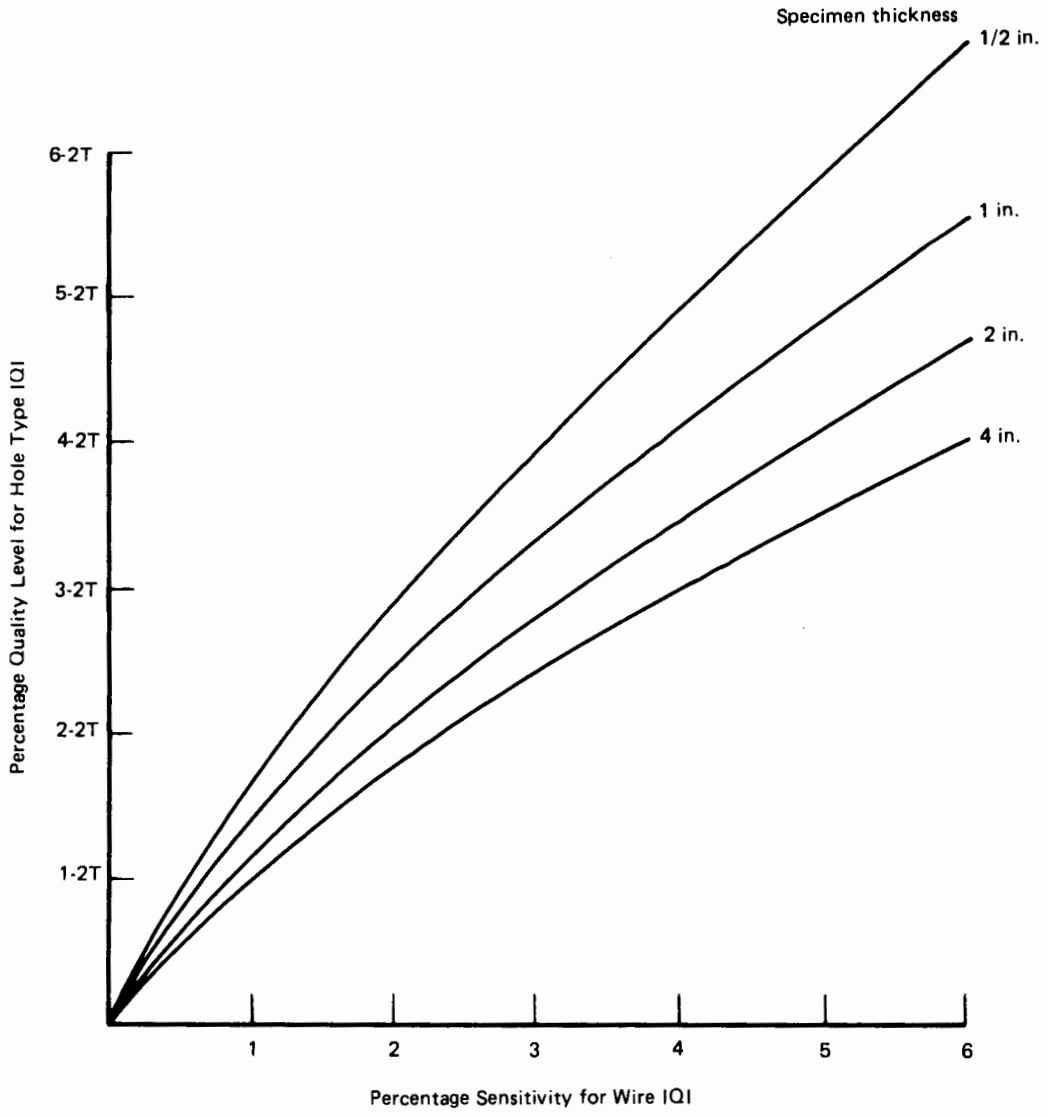


FIG. X1.1 CONVERSION CHART FOR 2-T QUALITY LEVEL HOLES TO PERCENTAGE WIRE SENSITIVITY

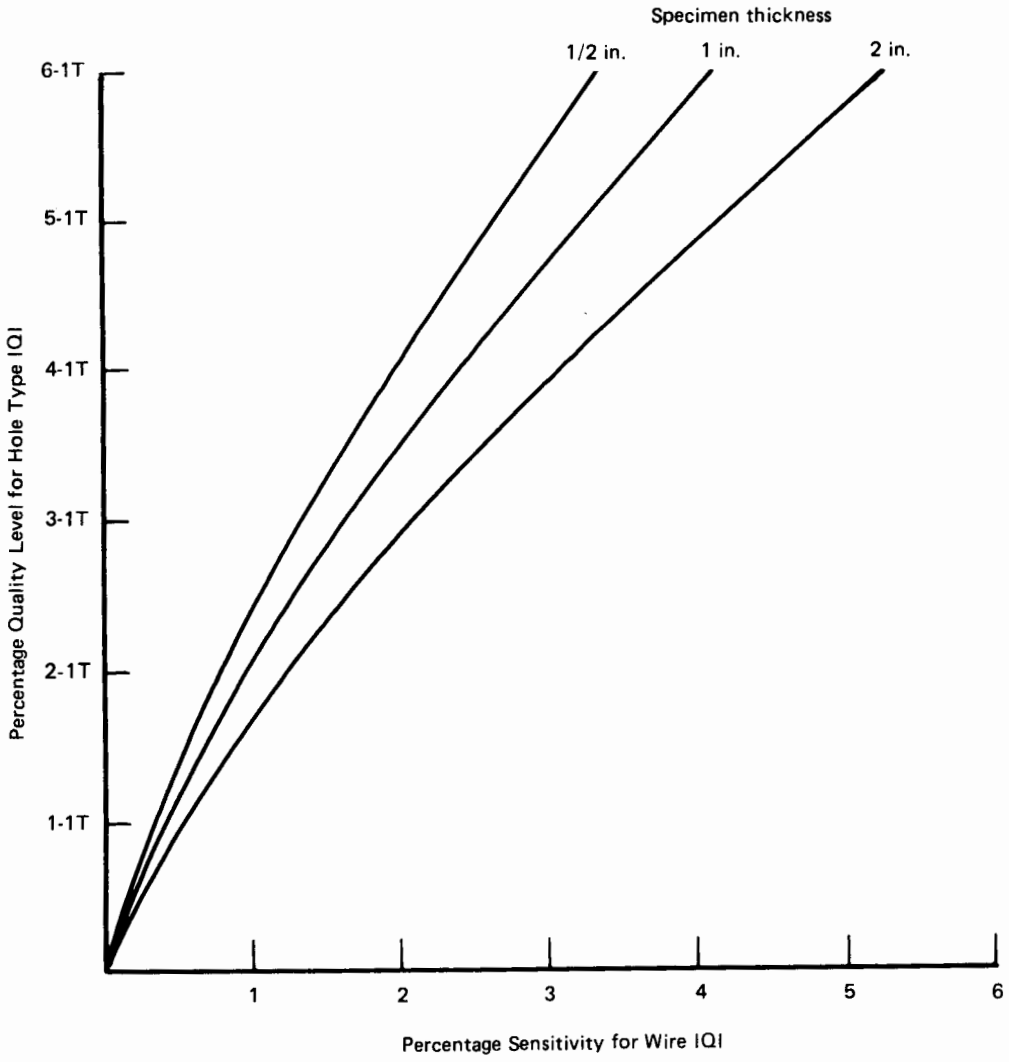


FIG. X1.2 CONVERSION CHART FOR 1-T QUALITY LEVEL HOLES TO PERCENTAGE WIRE SENSITIVITY

STANDARD GUIDE FOR CONTROLLING THE QUALITY OF INDUSTRIAL RADIOGRAPHIC FILM PROCESSING

SE-999

(Identical with ASTM Specification E 999-05.)

1. Scope

1.1 This guide establishes guidelines that may be used for the control and maintenance of industrial radiographic film processing equipment and materials. Effective use of these guidelines aid in controlling the consistency and quality of industrial radiographic film processing.

1.2 Use of this guide is limited to the processing of films for industrial radiography. This guide includes procedures for wet-chemical processes and dry processing techniques.

1.3 The necessity of applying specific control procedures such as those described in this guide is dependent, to a certain extent, on the degree to which a facility adheres to good processing practices as a matter of routine procedure.

1.4 If a nondestructive testing agency, as described in Practice E 543, is used to perform the examination, the testing agency shall meet the requirements of Practice E 543.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of federal and local codes prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 94 Guide for Radiographic Testing

E 543 Practice for Agencies Performing Nondestructive Testing

E 1079 Practice for Calibration of Transmission Densitometers

E 1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films

E 1316 Terminology for Nondestructive Examinations

2.2 *ANSI Standard:*

ANSI PH 4.8 Methylene Blue Method for Measuring Thiosulfate and Silver Densitometric Method for Measuring Residual Chemicals in Films, Plates, and Papers

3. Terminology

3.1 *Definitions* — For definitions of terms used in this guide, see Terminology E 1316.

4. Significance and Use

4.1 The provisions in this guide are intended to control the reliability or quality of the image development process only. The acceptability or quality of industrial radiographic films processed in this manner as well as the materials or products radiographed remain at the discretion of the user, or inspector, or both. It is further intended that this guide be used as an adjunct to and not a replacement for Guide E 94.

5. Chemical Mixing for Manual and Automatic Processes

5.1 Any equipment that comes in contact with processing solutions should be made of glass, hard rubber,

polyethylene, PVC, enameled steel, stainless steel, or other chemically inert materials. This includes materials such as plumbing, mixing impellers, and the cores of filter cartridges. Do not allow materials such as tin, copper, steel, brass, aluminum, or zinc to come into contact with processing solutions. These materials can cause solution contamination that may result in film fogging or rapid oxidation.

5.2 *Mixing Chemicals:*

5.2.1 Do not mix powdered chemicals in processor tanks, since undissolved particles may be left in the square corners of the tank. Mix solutions in separate containers made from materials specified in 5.1.

5.2.2 Carefully follow the manufacturer's package directions or formulas for mixing the chemicals. Start with the correct volume of water at the temperature specified in the instructions, and add chemicals in the order listed.

WARNING: During the mixing and use of photographic processing chemicals, be sure to observe all precautionary information on chemical containers and in instructions.

5.3 *Contamination of Solutions:*

5.3.1 Thoroughly clean all mixing equipment immediately after use to avoid contamination when the next solution is mixed. When mixing fixer from powder, make sure to add the powder carefully to the water in the mixing tank so that fixer dust does not get into other processing solutions. When mixing any chemical, protect nearby tank solutions with floating lids and dust covers. The use of a vent hood is recommended as a safety precaution.

5.3.2 The water supply should either be distilled or filtered so that it is clean and sediment-free.

5.3.3 If large tanks are used for mixing, carefully mark the volume levels to be certain that volumes are correct.

5.3.4 Use of impeller-type mixers provides rapid, thorough mixing. When positioning the impeller, special caution should be taken in choosing angle and depth to minimize the amount of air being drawn into the solution. Over-mixing of the solutions can cause oxidation, especially with developers, and should be avoided. Rinse the shaft, impeller, and mounting clamp with water after use.

5.4 *Maintaining Equipment:*

5.4.1 Immediately clean all mixing equipment after use.

5.4.2 In addition to cleaning equipment immediately after use, wash any mixing apparatus that has been idle for a long period of time to eliminate dust and dirt that may have accumulated.

5.4.3 Processing hangers and tanks should be free of corrosion and chemical deposits. Encrusted deposits that accumulate in tanks, trays, and processing equipment and that are difficult to remove by conventional cleaning can be removed by using the specially formulated cleaning agents recommended by the chemical or equipment manufacturer.

6. Storage of Solutions

6.1 *In Original Containers* — Follow the manufacturer's storage and capacity recommendations packaged with the chemicals. Do not use chemicals that have been stored longer than recommended.

6.2 *In Replenisher or Process Tanks* — Wherever possible, protect solutions in tanks with floating lids and dust covers. In addition to preventing contaminants from entering solutions, floating lids and dust covers help to minimize oxidation and evaporation from the surface of the solutions. Evaporation can concentrate solutions and reduce temperatures causing precipitation of some of the solution constituents.

6.2.1 Store replenisher solutions for small volume operations in airtight containers. The caps of these containers should be free of corrosion and foreign particles that could prevent a tight fit.

6.3 *Temperature* — Store all solutions at normal room temperature, between 40 to 80°F (4 to 27°C). Storing solutions, particularly developer, at elevated temperatures can produce rapid oxidation resulting in loss of activity and a tendency to stain the film. Storage at too low a temperature, particularly of fixer solutions, can cause some solutions to crystallize, and the crystals may not redissolve even with heating and stirring.

6.4 *Deterioration* — Radiographic film processing chemicals can deteriorate either with age or with usage. Carefully follow the manufacturer's recommendations for storage life and useful capacity. Discard processing solutions when the recommended number of films have been processed or the recommended storage life of the prepared solution has been reached, whichever occurs first.

6.5 *Contamination:*

6.5.1 Liquid chemicals are provided in containers with tight-fitting tops. To avoid contamination, never interchange the top of one container with another. For this reason, it is common practice for radiographic film processing chemical manufacturers to color code the container tops, that is, red for developer and blue for fixer.

6.5.2 Clearly label replenisher storage tanks with the solution that they contain and use that container only with that solution. If more than one developer or one

fixer formulation are being used, a separate replenisher tank should be dedicated to each chemical. Differences in developer or fixer formulations from one manufacturer to another may contaminate similar solutions.

7. Processing

7.1 *Manual Processing:*

7.1.1 Follow the temperature recommendations from the film or solution manufacturer and check thermometers. Check thermometers and temperature-controlling devices periodically to be sure that the process temperatures are correct. Process temperatures should be checked at least once per shift. Keep the temperature of the stop (if used), fixer, and wash water within ±5°F (±3°C) of the developer temperature.

WARNING: An unprotected mercury-filled thermometer should never be used for radiographic film processing applications because accidental breakage could result in serious mercury contamination.

7.1.2 Control of processing solution temperature and immersion time relationships are instrumental considerations when establishing a processing procedure that will consistently produce radiographs of desired density and quality. The actual time and temperature relationships established are governed largely by the industrial radiographic films and chemicals used and should be within the limits of the manufacturer's recommendations for those materials. When determining the immersion time for each solution, assure that the draining time is included. Draining time should be consistent from solution to solution. The darkroom timers used should be periodically checked for accuracy.

7.1.3 Agitate at specified intervals for the times recommended by the film or solution manufacturer.

7.1.4 During film processing certain constituents within the solutions undergo chemical transformations that render them useless for further processing functions. In addition, some solution adheres to the film and is carried on into the next solution during processing. In order to compensate for these reductions in solution activity and volume, add replenishment solution. The volume of replenishment necessary is governed primarily by the number, size, and density of films processed. Manufacturer's recommendations for replenishment are based on these criteria and will generally provide suitable results for the expected life of the solution. In any case, maintain solution levels to ensure complete immersion of the film.

7.1.5 The functional constituents in a freshly mixed developer solution tend to overreact on the initial films processed and may develop unexposed areas on the films. For this reason, measures should be taken to stabilize the activity of the solution and thus *season* the developer. This can be accomplished by the use of developer starter solution or by processing a series of *seasoning films* (see Note 1) in the freshly mixed solution. When using developer starter solution follow the manufacturer's recommendations for the product. When using seasoning films expose the films with visible light and then develop these films in the solution to be seasoned. Use three 14 by 17-in. (35 by 43-cm) films, or equivalent, per gallon (3.8 L) of developer.

NOTE 1 — Seasoning films may be new films or films that may not be generally suitable for production purposes due to excessive gross fog (base plus fog) density, expiration of shelf life, or other reasons.

7.1.6 Handle all films carefully during the processing cycle and allow adequate time for the film to sufficiently drain before transferring it to the next solution. The use of a stop bath or clear water rinse between developing and fixing may also be appropriate. The stop bath or clear water rinse serves to arrest development and also aids in minimizing the amount of developer carried over into the fixer solution. Insufficient bath-to-bath drain time may cause excessive solution carry-over which can contaminate and shorten the life of solutions in addition to causing undesirable effects on processed radiographs.

7.1.7 When washing films, a wettening agent may be appropriate to use to prevent water spots and streaking during drying.

WARNING: Prior to placing films in the dryer, ensure that the dryer is clean and that adequate heat and ventilation are provided. During drying, visually examine the films to determine the length of time required for sufficient drying.

7.2 *Automated Processing:*

7.2.1 Immersion time and solution temperature relationships can be more closely controlled with automatic processing since the equipment provides external gages for monitoring purposes. As a general guideline, follow the manufacturer's recommendations for industrial processing materials. However, the actual procedure used should be based on the variables encountered by the user and his particular needs. Check solutions daily or with established frequency based upon usage to ensure that temperatures are within the manufacturer's recommendations. Check the processor's thermometer with a secondary thermometer during normal maintenance procedures to verify correct processing temperatures within the manufacturer's specifications.

7.2.2 Transport speed should be checked during normal maintenance procedures by measuring the time it takes for a given length of film to pass a specific point. (For example, if the indicated machine speed is 2 ft/min, place two marks on a length of film 1 ft apart. The second

mark should pass a specific location, such as the entrance to the processor, exactly 30 s after the first mark has passed the same point.) An optional method for measuring processor speed is to install a tachometer on the main drive motor and determine desired RPM/processing speed relationships.

7.2.3 Agitation is provided by the action of the processor rollers, recirculation pumps, wash water flow, and no external agitation is needed.

7.2.4 For processors with replenishment systems, use the replenishment rates recommended by the film or solution manufacturer.

7.2.4.1 Accurate replenishment increases the useful life of solutions to a great extent by replacing ingredients that are depleted and maintains the process at a constant, efficient level.

7.2.4.2 Replenisher rates should be verified during normal maintenance procedures to ensure that correct volumes are being injected into the solutions. For installations processing very large amounts of film (in excess of two tank turnovers of replenisher per week), checks on replenishment rates should be made more frequently. Processor manufacturer's recommendations will generally provide an adequate procedure for checking replenishment volumes.

7.2.5 For seasoning freshly mixed developer solution, refer to the provisions in 7.1.5.

7.2.6 Always fill the fixer tank first, following the manufacturer's instructions, then rinse and fill the developer tank. This minimizes the possibility of fixer accidentally splashing into the developer solution. When replacing or removing processor racks, always use a splash guard to further reduce the possibility of contamination.

7.2.7 *Drying:*

7.2.7.1 Make sure the dryer is clean and that no foreign material has settled on the rollers. Routinely examine the ventilation system to ensure that air paths are not blocked and that films are uniformly dried. There are two types of dryer systems used in automatic film processors for industrial radiographic films:

(1) Convection dryers are circulating air systems with thermostatic controls. Normal drying temperatures range from 80 to 120°F when relative humidity (RH) conditions are approximately 40 to 75%. Relative humidities above 75% may require higher temperatures.

(2) Infrared (IR) dryers are based principally on absorption rather than temperature. Relative humidity has no adverse affect on infrared drying. Infrared energy levels are preset by the manufacturer and provide a range of dryer settings.

7.2.7.2 The dryer efficiency can be tested by processing six consecutive 14 by 17-in. (35 by 43-cm) production films, or equivalent, and examining them immediately after the drying cycle is complete. If damp or undried areas are observed, increase the dryer setting. Should an increase in dryer temperature for convection dryers or an increase in energy for infrared dryers not dry the film, the following conditions should be investigated:

(1) Wash water that is too warm will cause excessive emulsion swelling. This can adversely affect film drying in convection dryers.

(2) Incoming dryer air that is either too humid or too cold can adversely affect film drying in the convection dryer.

(3) Check if oven-temperature devices or IR radiators, or both, are operational in infrared dryers.

(4) The fixer solution activity may not be in accordance to manufacturing recommendations and should be tested in accordance with 8.6.

7.3 *Dry Processing:*

7.3.1 Follow manufacturer's recommendations for thermal processor warm-up requirements.

7.3.2 Follow time-temperature recommendations from the manufacturer.

8. Activity Testing of Solutions for Manual and Automatic Processing

8.1 To establish a reliable procedure for determining the activity of processing solutions, it will be necessary to provide a minimal amount of equipment and the proper selection and storage of radiographic control films.

8.2 *Sensitometric Step Tablets:*

8.2.1 A metallic step wedge or other suitable object(s) of uniform material and varying thickness(es), of either aluminum or steel can be used with a given X-ray or gamma-ray exposure to create a sensitometric control strip.

8.2.2 Electronic sensitometers and pre-exposed sensitometric control strips are also commercially available. The user of electronic sensitometers (film exposed to white light) should be aware that such usage, when accompanied by an appropriate white-light sensitive industrial film, results in greater response. Consequently, maintenance of developing parameters must be at a higher and more frequent level.

8.3 *Radiographic Monitoring Films* — Radiographic films are made in batches where the characteristics may vary slightly between batches. These changes from emulsion to emulsion may be detectable and could be confused with the changes in the radiographic processing system.

8.3.1 Monitoring films must be properly stored to ensure that the film characteristics of the first sheet will be the same as the last sheet used. See Guide E 1254.

8.3.2 A monitoring film should be the same brand and type predominantly used in the facilities processing system.

8.3.3 The first sensitometric film processed through freshly mixed and seasoned chemistry (see 7.1.5) will become the reference or standard for a box of control film.

8.3.4 Subsequent monitoring films are then produced on an as-needed basis and compared to the reference film to determine sensitometric changes within the processor. Generally, the higher the film volume processed, the more often QA checks should be performed.

8.3.5 If a monitoring film produces unusually high or low densities exceeding the tolerance limits, then the processing and sensitometric exposure conditions should be rechecked and repeated, if necessary. If the results are still out of tolerance, the cause must be located and corrected. Generally, a small adjustment in replenishment rates is necessary until a sensitometric film processor activity balance is established.

8.3.6 Whenever a new monitoring film becomes necessary to change from one emulsion to another, two films each (from the new box and the old box) should be exposed and processed simultaneously to adjust for normal film manufacturing sensitometric variations.

8.4 *Densitometer:*

8.4.1 A transmission densitometer should be used capable of reading densities from 0.0 to 4.0, with an aperture on the order of 1.0 to 3.0 mm in diameter. The densitometer should be calibrated in accordance with Practice E 1079.

8.5 *Developer:*

8.5.1 The developer activity should be checked by processing a pre-exposed sensitometric strip, a radiograph of a step wedge, or a test part for measuring four film densities, one at base + fog (unexposed area of film) and three between 1.5 and 4.0 in three areas of interest (high, medium, and low densities). These four areas are also known as the Aim Film densities.

8.5.2 The film densities in the areas of interest being monitored should be within ±10% of the original monitoring film density. Variations within this range are generally considered normal and should not adversely affect radiographic quality.

8.6 *Fixer:*

8.6.1 Fixer solution activity can be determined by measuring the clearing time. After the fixer solution has reached an operating temperature, place an unprocessed X-ray film into the fixer solution and measure the time required to remove the silver halide crystals; this is known as the clearing time. Removal of the X-ray film silver halide crystals can be observed when the X-ray film turns from a reflective color to a clear transluscent film in the fixer. Clearing time should be 25% less than the fixer immersion time. The film should be periodically agitated during manual processing.

8.6.2 If physical examination shows unfixed spots or areas, the fixer should be discarded. Unfixed areas may appear as dull, nonreflective areas that may be yellowish in color depending on the actual lack of fixer activity.

8.7 *Wash:*

8.7.1 Proper washing is necessary to remove residual fixer from the film. If not removed from the film, these chemicals will cause subsequent damage (staining) and deterioration of the radiographic image, especially in low-density areas.

8.7.2 The effectiveness of washing may be checked using the *residual thiosulphate chemicals* test described in Guide E 94 or ANSI PH4.8.

8.7.3 If physical examination of the films after washing shows dirt or scum that was not present before washing, the wash tanks should be drained and cleaned. Drain wash tanks whenever they are not being used. In order to minimize washing artifacts, it is recommended that *scavenger films* be processed at start up to clear out scum and foreign material; the use of algaecides is also recommended to retard the growth of organisms within the wash bath.

8.7.4 The newer cold-water-type processors do not require a control valve to regulate water temperatures. However, many older-type processors require that the incoming water temperature be set within certain limits of the developer temperature. Exceeding these limits may not allow the processor to adequately control the developer temperature, which may cause density variations.

9. Records

9.1 Accurate records should be kept of the following items:

9.1.1 Brand name and model of processor, if used.

9.1.2 Brand names and batch number of chemicals used.

9.1.3 Time of development.

9.1.4 Temperature of processing chemicals.

9.1.5 Date new chemicals were placed in use.

9.1.6 Replenishment rates.

10. Maintenance

10.1 Maintenance schedules provided by the manufacturer for preventive maintenance should be adhered to in order to assure consistent chemical and mechanical operation as set forth by the manufacturer.

11. Keywords

11.1 automatic processing; film; manual processing; processing; radiographic; solutions

STANDARD PRACTICE FOR DESIGN, MANUFACTURE, AND MATERIAL GROUPING CLASSIFICATION OF HOLE-TYPE IMAGE QUALITY INDICATORS (IQI) USED FOR RADIOLOGY

A06

SE-1025

(Identical with ASTM Specification E 1025-05.)

1. Scope

1.1 This practice covers the design, material grouping classification, and manufacture of hole-type image quality indicators (IQI) used to indicate the quality of radiologic images.

1.2 This practice is applicable to X-ray and gamma-ray radiology.

1.3 The values stated in inch-pound units are to be regarded as standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 139 Specification for Phosphor Bronze Rod, Bar, and Shapes

B 150 Specification for Aluminum Bronze Rod, Bar, and Shapes

B 161 Specification for Nickel Seamless Pipe and Tube

B 164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire

B 166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, and N06690) and Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) Rod, Bar, and Wire

E 1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions* — The definitions of terms relating to gamma and x-radiology in Terminology E 1316, Section D, shall apply to the terms used in this practice.

4. Hole-Type IQI Requirements

4.1 Image quality indicators (IQIs) used to determine radiologic-image quality levels shall conform to the following requirements.

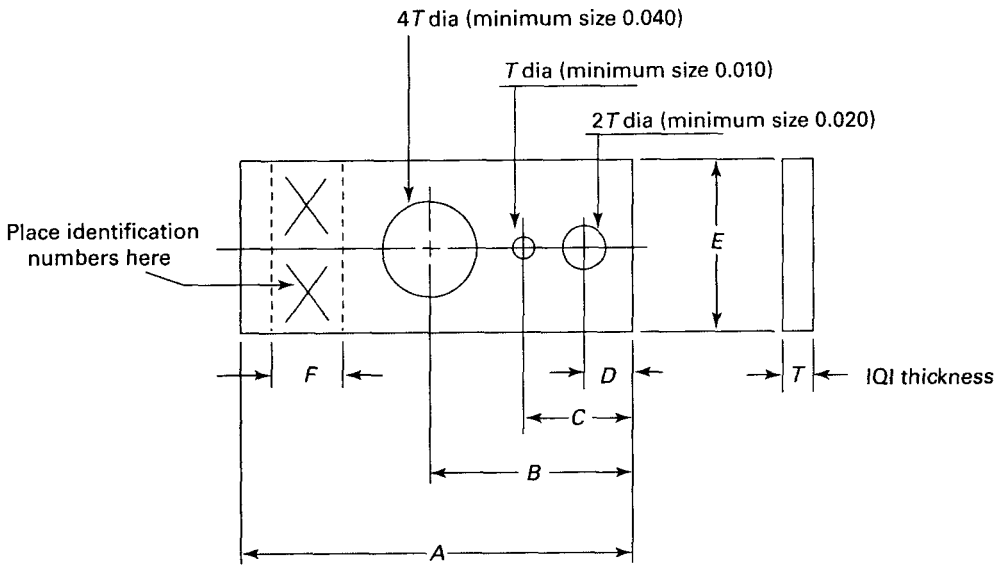
4.1.1 *Standard Hole-Type IQIs:*

4.1.1.1 Image quality indicators (IQIs) shall be fabricated from materials or alloys identified or listed in accordance with 7.3. Other materials may be used in accordance with 7.4.

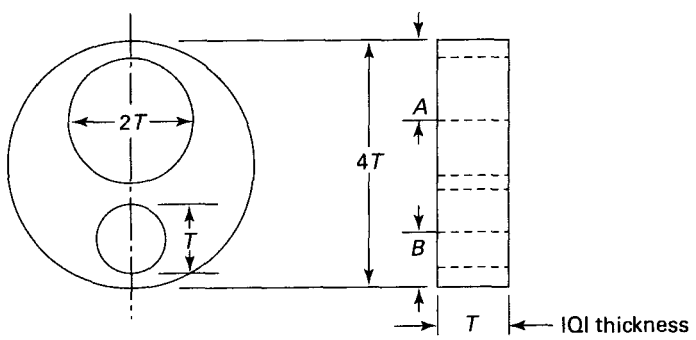
4.1.1.2 Image quality indicators (IQIs) shall dimensionally conform to the requirements of Fig. 1.

4.1.1.3 Both the rectangular and the circular IQI shall be identified with number(s) made of lead or a material of similar radiation opacity. The number shall be bonded to the rectangular IQIs and shall be placed adjacent to circular IQIs to provide identification of the IQI on the image. The identification numbers shall indicate the thickness of the IQI in thousandths of an inch, that is, a number 10 IQI is 0.010 in. thick, a number 100 IQI is 0.100 in. thick, etc. Additional identification requirements are provided in 7.2.

4.1.1.4 Alloy-group identification shall be in accordance with Fig. 2. Rectangular IQIs shall be notched. Image quality indicators (IQIs) shall be vibro-tooled or etched as specified.



(a) Design for IQIs to and Including 160



(b) Design for IQIs Over 160

Note 1 — All dimensions in inches (Note 6).
Note 2 — Tolerances for IQI thickness and hole diameter.
Note 3 — XX identification number equals *T* in 0.001 inches.
Note 4 — IQIs No. 1 through 9 are not *1T*, *2T*, and *4T*.
Note 5 — Holes shall be true and normal to the IQI. Do not chamfer.
Note 6 — To convert inch dimensions to metric, multiply by 25.4.

Identification Number *T* (Note 3)	*A*	*B*	*C*	*D*	*E*	*F*	Tolerances (Note 2)
1–4	1.500 ± 0.015	0.750 ± 0.015	0.438 ± 0.015	0.250 ± 0.015	0.500 ± 0.015	0.250 ± 0.030	± 10%
5–20	1.500 ± 0.015	0.750 ± 0.015	0.438 ± 0.015	0.250 ± 0.015	0.500 ± 0.015	0.250 ± 0.030	± 0.0005
21–50	...	...	...	...	...	...	± 0.0025
Over 50–160	2.250 ± 0.030	1.375 ± 0.030	0.750 ± 0.030	0.375 ± 0.030	1.000 ± 0.030	0.375 ± 0.030	± 0.005
Over 160	1.330T ± 0.005	0.830T ± 0.005	...	...	...	...	± 0.010

FIG. 1 IQI DESIGN

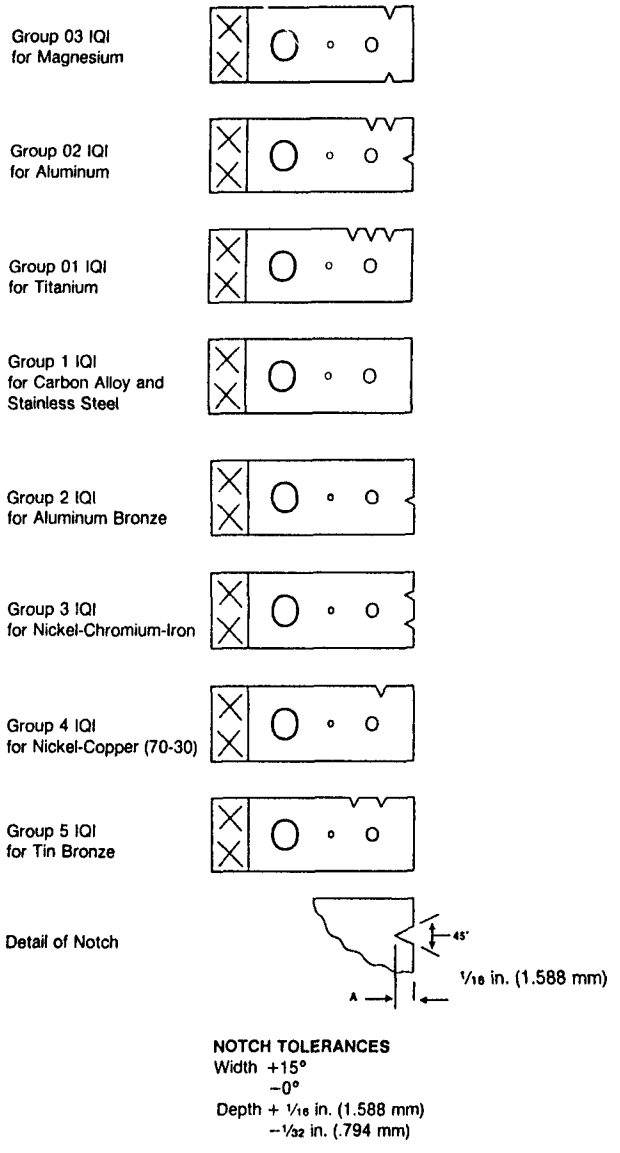


FIG. 2 RECTANGULAR IQI NOTCH IDENTIFICATION AND MATERIAL GROUPING

4.1.2 *Modified Hole-Type IQI:*

4.1.2.1 The rectangular IQI may be modified in length and width as necessary for special applications, provided the hole size(s) and IQI thickness conform to Fig. 1.

4.1.2.2 The IQIs shall be identified as specified in 4.1.1.3, except that the identification numbers may be placed adjacent to the IQI if placement on the IQI is impractical.

4.1.2.3 When modified IQIs are used, details of the modification shall be documented in the records accompanying the examination results.

TABLE 1
TYPICAL IMAGE QUALITY LEVELS

Image Quality Levels	IQI Thickness	Minimum Perceptible Hole Diameter	Equivalent IQI Sensitivity, %[B]
Standard Image Quality Levels			
2-1*T*	1/50 (2%) of Specimen Thickness	1*T*	1.4
2-2*T*[A]		2*T*	2.0
2-4*T*		4*T*	2.8
Special Image Quality Levels			
1-1*T*	1/100 (1%) of Specimen Thickness	1*T*	0.7
1-2*T*		2*T*	1
4-2*T*	1/25 (4%) of Specimen Thickness	2*T*	4

[A]For *Level 2-2T Radiologic* — The 2*T* hole in an IQI, 1/50 (2%) of the specimen thickness, is visible.
[B]Equivalent IQI sensitivity is that thickness of the IQI, expressed as a percentage of the part thickness, in which the 2*T* hole would be visible under the same conditions.

5. IQI Procurement

5.1 When selecting IQIs for procurement, the following factors should be considered:

5.1.1 Determine the alloy group(s) of the material to be examined.

5.1.2 Determine the thickness or thickness range of the material(s) to be examined.

5.1.3 Select the applicable IQIs that represent the required IQI thickness and alloy(s).

NOTE 1 — This practice does not recommend or suggest specific IQI sets to be procured. Section 5 is an aid in selecting IQIs based on specific needs.

6. Image Quality Levels

6.1 Image quality levels are designated by a two part expression *X-YT*. The first part of the expression *X* refers to the IQI thickness expressed as a percentage of the specimen thickness. The second part of the expression *YT* refers to the diameter of the hole and is expressed as a multiple of the IQI thickness, *T*. The image quality level 2-2*T* means that the IQI thickness *T* is 2% of the specimen thickness and that the diameter of the IQI imaged hole is 2 × the IQI thickness.

NOTE 2 — Image Quality Indicators (IQIs) less than number 10 have hole sizes 0.010, 0.020, and 0.040 in. diameter regardless of the IQI thickness. Therefore, IQIs less than number 10 do not represent the quality levels specified in 6.1 and Table 1. The equivalent sensitivity can be computed from data furnished in Appendix X1.

6.2 Typical image quality level designations are shown in Table 1. The level of inspection specified should be based on service requirements of the product. Care should be taken in specifying image quality levels 2-1*T*,

1-1*T*, and 1-2*T* by first determining that these levels can be maintained in production.

6.3 In specifying image quality levels, the contract, purchase order, product specification, or drawing should state the proper two-part expression and clearly indicate the thickness of the metal to which the level refers. In place of a designated two-part expression, the IQI number and minimum discernible hole size shall be specified.

6.4 Appendix X1 of this practive provides methods for determining equivalent penetrameter sensitivity (EPS) in percent. Under certain conditions (as described within the purcahaser-supplier agreement), EPS may be useful in relating a discerning hole size of the IQI thickness with the section thickness radiographed for establishing an overall technical image quality equivalency. This is not an altenative IQI provision for the originally specified IQI requirement of this practice, but may be a useful tool for establishing technical image equivalency on a case basis need with specific customer approvals.

6.5 Practice E 747 contains provisions for wire IQIs that use varying length and diameter wire to affect image quality requirements. The requirements of Practice E 747 are different from this standard; however, Practice E 747 (see Table 4) contains provisions whereby wire sizes equivalent to corresponding 1*T*, 2*T*, and 4*T* holes for various plaque thicknesses are provided. Appendix X1 of Practice E 747 also provides methods for determining equivalencies between wire and hole type IQIs. This is not an alternative IQI provision for the originally specified IQI requirements of this practice, but may be useful for establishing technical image equivalency on a case basis need with specific customer approvals.

6.6 Test Methods E 746 and E 1735 provide additional tools for determining relative image quality response of industrial radiographic film systems when exposed to energy levels described within those test methods. Both of these test methods use the "equivalent penetrameter sensitivity" (EPS) concept to provide statistical image quality information that allows the film system of other exposure components to be assessed on a relative basis. These test methods are not alternative IQI provisions for the orginally specified IQI requirements of this practice, but may be useful on a case basis with specific customer approvals, for establishing technical image equivalency of certain aspects of the radiographic imaging process.

7. Material Groups

7.1 *General:*

7.1.1 Materials have been designated in eight groups based on their radiation absorption characteristics: Groups 03, 02, and 01 for light metals and Groups 1 through 5 for heavy metals.

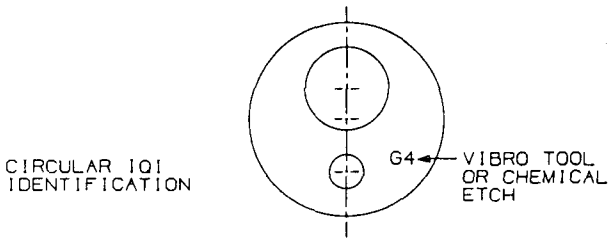


FIG. 3 CIRCULAR IQI IDENTIFICATION

7.1.2 The light metal groups, magnesium (Mg), aluminum (A1), and titanium (Ti), are identified 03, 02, and 01 respectively for their predominant alloying constituent. The materials are listed in order of increasing radiation absorption.

7.1.3 The heavy metal groups, steel, copper base, nickel base, and kindred alloys, are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

NOTE 3 — These groups were established experimentally at 180 kV on $\frac{3}{4}$-in. (19-mm) thick specimens. They apply from 125 kV to the multivolt range.

7.1.4 Common trade names or alloy designations have been used for clarification of the pertinent materials.

7.1.5 The materials from which the IQI for the group are to be made are designated in each case, and these IQIs are applicable for all materials listed in that group. In addition, any group IQI may be used for any material with a higher group number, provided the applicable quality level is maintained.

7.2 *Identification System:*

7.2.1 A notching system has been designated for the eight groups of IQIs and is shown in Fig. 2.

7.2.2 For circular IQIs, a group designation shall be vibrotooled or chemically etched on the IQI to identify it by using the letter "G" followed by the group number, that is, G4 for a Group 4 IQI. For identification of the group on the image, corresponding lead characters shall be placed adjacent to the circular IQI, just as is done with the lead numbers identifying the thickness. The identification is shown in Fig. 3.

7.3 *Materials Groups:*

7.3.1 *Materials Group* 03:

7.3.1.1 Image quality indicators (IQIs) shall be made of magnesium or magnesium shall be the predominant alloying constituent.

7.3.1.2 Use on all alloys of which magnesium is the predominant alloying constituent.

7.3.2 *Materials Group* 02:

7.3.2.1 Image quality indicators (IQIs) shall be made of aluminum or aluminum shall be the predominant alloying constituent.

7.3.2.2 Use on all alloys of which aluminum is the predominant alloying constituent.

7.3.3 *Materials Group* 01:

7.3.3.1 Image quality indicators (IQIs) shall be made of titanium or titanium shall be the predominant alloying constituent.

7.3.3.2 Use on all alloys of which titanium is the predominant alloying constituent.

7.3.4 *Materials Group* 1:

7.3.4.1 Image quality indicators (IQIs) shall be made of carbon steel or Type 300 series stainless steel.

7.3.4.2 Use on all carbon steel, all low-alloy steels, all stainless steels, manganese-nickel-aluminum bronze (Superston).

7.3.5 *Materials Group* 2:

7.3.5.1 Image quality indicators (IQIs) shall be made of aluminum bronze (Alloy No. 623, of Specification B 150) or equivalent, or nickel-aluminum bronze (Alloy No. 630 of Specification B 150) or equivalent.

7.3.5.2 Use on all aluminum bronzes and all nickel-aluminum bronzes.

7.3.6 *Materials Group* 3:

7.3.6.1 Image quality indicators (IQIs) shall be made of nickel-chromium-iron alloy (UNS No. N06600) (Inconel). (See Specification B 166.)

7.3.6.2 Use on nickel-chromium-iron alloy and 18% nickel-maraging steel.

7.3.7 *Materials Group* 4:

7.3.7.1 Image quality indicators (IQIs) shall be made of 70 to 30 nickel-copper alloy (Monel) (Class A or B of Specification B 164) or equivalent, or 70 to 30 copper-nickel alloy (Alloy G of Specification B 161) or equivalent.

7.3.7.2 Use on nickel, copper, all nickel-copper series, or copper-nickel series of alloys, and all brasses (copper-zinc alloys). Group 4 IQIs may be used on the leaded brasses, since leaded brass increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

7.3.8 *Materials Group* 5:

7.3.8.1 Image quality indicators (IQIs) shall be made of tin bronze (Alloy D of Specification B 139).

7.3.8.2 Use on tin bronzes including gun-metal and valve bronze, leaded-tin bronze of higher lead content than valve bronze. Group 5 IQIs may be used on bronze of higher lead content since leaded bronze increases in attenuation with increase in lead content. This would be equivalent to using a lower group IQI.

NOTE 4 — In developing the eight listed materials groups, a number of other trade names or other nominal alloy designations were evaluated. For the purpose of making this practice as useful as possible, these materials are listed and categorized, by group, as follows:

(1) Group 2 — Haynes Alloy IN-100.

(2) Group 3 — Haynes Alloy No. 713C, Hastelloy D, G.E. Alloy SEL, Haynes Stellite Alloy No. 21, GMR-235 Alloy, Haynes Alloy No. 93, Inconel X, Inconel 718, and Haynes Stellite Alloy No. S-816.

(3) Group 4 — Hastelloy Alloy F, Hastelloy Alloy X, and Multimeter Alloy Rene 41.

(4) Group 5 — Alloys in order of increasing attenuation: Hastelloy Alloy B, Hastelloy Alloy C, Haynes Stellite Alloy No. 31, Thetaloy, Haynes Stellite No. 3, Haynes Alloy No. 25. IQIs of any of these materials are considered applicable for the materials that follow it.

NOTE 5 — The committee formulating these recommendations recommended other materials may be added to the materials groups listed as the need arises or as more information is gained, or that additional materials groups may be added.

7.4 *Radiographic Method for Other Materials:*

7.4.1 For materials not herein covered, IQIs of the same materials, or any other material, may be used if the following requirements are met. Two blocks of equal thickness, one of the material to be examined (production material) and one of the IQI material, shall be radiographed on one film by one exposure at the lowest energy level to be used for production. Transmission densitometer readings for both materials shall be read from the film and shall be between 2.0 and 4.0 (radiographic) density for both materials. If the radiographic image density of the material from which the IQIs are to be fabricated is within +15 to −0% of the radiographic image density of the production material, the IQI material may be used to fabricate IQIs for examination of the production material. The percentage figure is based on the radiographic density of the IQI material.

7.4.2 It shall always be permissible to use IQIs of similar composition as the material being examined.

8. IQI Certification

8.1 Records shall be available that attest to the conformance of the material type, grouping (notches), and dimensional tolerances of the IQIs specified by this practice.

9. Precision and Bias

9.1 *Precision and Bias* — No statement is made about the precision or bias for indicating the quality of radiographs since the results merely state whether there is conformance to the criteria for success specified in this practice.

10. Keywords

10.1 density; image quality level; IQI; radiologic; radiology; X-ray and gamma radiation

APPENDIX

(Nonmandatory Information)

X1. EQUIVALENT IQI (PENETRAMETER) SENSITIVITY (EPS)

X1.1 To find the equivalent IQI sensitivity (percent), the hole size (diameter in inches), of the IQI thickness (inches), for a section thickness (inches), the following computations may be used:

$$\alpha = \frac{100}{X}\sqrt{\frac{TH}{2}},$$

where:

α = equivalent IQI sensitivity, %,
X = section thickness to be examined, in.,
T = IQI thickness, in., and
H = hole diameter, in.

X1.2 Alternate method for determining EPS using Fig. X1.1 Nomograph:

Example:

Given:

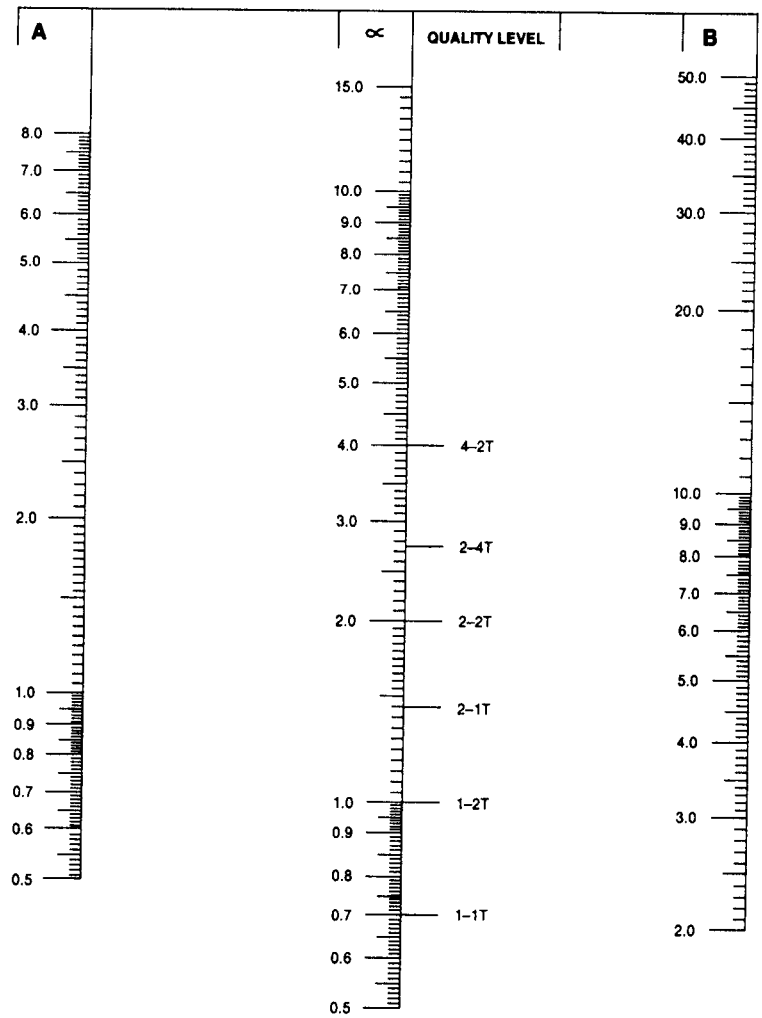
X = 0.5 in.
T = 0.005 in., and
H = 0.0625 in.

Solution:

$$A = \frac{100T}{X} = \frac{100 \times 0.005}{0.5} = 1.0\%$$

$$B = \frac{100H}{X} = \frac{100 \times 0.0625}{0.5} = 12.5\%$$

X1.3 Proceed to the nomograph (Fig. X1.1) and draw a line joining the 1.0% Value A and the 12.5% Value B and look on the center percent scale where the line crosses it and read the answer — 2.5%. Thus under the given conditions, equivalent IQI (penetrameter) sensitivity (EPS) is 2.5%.



Definitions:

A equals the visible IQI (penetrameter) plaque thickness (*T*) expressed as a percentage of the section (object) thickness to be radiographed in (inches).

B equals the diameter of the smallest IQI (penetrameter) hole (*H*) for which the image is visibly expressed as a percentage of the section (object) thickness to be radiographed in (inches).

Note — The nomograph is used for computing equivalent IQI sensitivity from *T* (*T* equals penetrameter thickness) inches and *H* (*H* equals hole diameter) inches. Draw a straight line joining the values on any two scales, and look on the third scale where the line crosses and read the answer. Due to normal reproduction methods in producing the nomograph, some small error (that is, less than 5%) may occur. If more accurate results are required, the formula in Appendix X1 should be used.

FIG. X1.1 EQUIVALENT IQI (PENETRAMETER) SENSITIVITY NOMOGRAPH

STANDARD TEST METHOD FOR RADIOGRAPHIC EXAMINATION OF METALLIC CASTINGS

SE-1030

(Identical with ASTM Specification E 1030-00)

1. Scope

1.1 This test method provides a uniform procedure for radiographic examination of metallic castings using radiographic film as the recording medium.

1.2 Due to the many complex geometries and part configurations inherent with cast products, it is necessary to recognize potential limitations associated with obtaining complete radiographic coverage on castings. Radiography of areas where geometry or part configuration does not allow achievement of complete coverage with practical radiographic methods shall be subject to mutual agreements between purchaser and supplier. The use of alternative nondestructive methods for areas that are not conducive to practical radiography shall also be specifically agreed upon between purchaser and supplier.

1.3 The radiographic method is highly sensitive to volumetric discontinuities that displace a detectable volume of cast material. Discontinuities that do not displace an appreciable volume of material, however, such as cracks or other planar-type indications, may not be detected with radiography unless the radiation beam is coincidentally aligned with the planar orientation of the discontinuity. In view of this limitation, it may be considered appropriate to use the radiographic method in conjunction with additional nondestructive methods that maintain reliable detection capabilities for these types of discontinuities. The use of additional methods shall be specifically agreed upon between the purchaser and supplier.

1.4 The values stated in inch-pound units are to be regarded as standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 94 Guide for Radiographic Examination

E 155 Reference Radiographs for Inspection of Aluminum and Magnesium Castings

E 186 Reference Radiographs for Heavy-Walled [2 to 4½-in. (51 to 114-mm)] Steel Castings

E 192 Reference Radiographs for Investment Steel Castings for Aerospace Applications

E 272 Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Alloy Castings

E 280 Reference Radiographs for Heavy-Walled [4½ to 12-in. (114 to 305-mm)] Steel Castings

E 310 Reference Radiographs for Tin Bronze Castings

E 446 Reference Radiographs for Steel Castings Up to 2 in. (51 mm) in Thickness

E 505 Reference Radiographs for Inspection of Aluminum and Magnesium Die Castings

E 543 Practice for Agencies Performing Nondestructive Testing

E 689 Reference Radiographs for Ductile Iron Castings

E 746 Test Method for Determining Relative Image Quality Response of Industrial Radiographic Film

E 747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E 802 Reference Radiographs for Gray Iron Castings Up to 4½-in. (114 mm) in Thickness

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E 1254 Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films

E 1316 Terminology for Nondestructive Examinations

E 1815 Test Method for Classification of Film Systems for Industrial Radiography

2.2 *ASNT/ANSI Standards:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

CP-189 Qualification and Certification of Nondestructive Testing Personnel

2.3 *Other Standards:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

NAS 410 National Aerospace Standard Certification and Qualification of Nondestructive Test Personnel

3. Terminology

3.1 *Definitions* — For definitions of terms used in this test method, see Terminology E 1316.

4. Significance and Use

4.1 The requirements expressed in this test method are intended to control the quality of the radiographic images, to produce satisfactory and consistent results, and are not intended for controlling the acceptability or quality of materials or products.

5. Basis of Application

5.1 The following items shall be agreed upon by the purchaser and supplier:

5.1.1 *Nondestructive Testing Agency Evaluation* — If specified in the contractual agreement, nondestructive testing (NDT) agencies shall be qualified and evaluated in accordance with Practice E 543. The applicable version of Practice E 543 shall be specified in the contractual agreement.

5.1.2 *Personnel Qualification* — NDT personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, MIL-STD-410, NAS 410 or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

5.1.3 *Requirements* — General requirements (see 8.1, 8.2, 8.5, and 8.7.4) shall be specified.

5.1.4 Procedure Requirements (see 9.1, 9.1.1, 9.3, and 9.7.7) shall be specified.

5.1.5 *Records* — Record retention (see 12.1) shall be specified.

6. Apparatus

6.1 *Radiation Sources:*

6.1.1 *X Radiation Sources* — Selection of appropriate X-ray voltage and current levels is dependent upon variables regarding the specimen being examined (material type and thickness) and economically permissible exposure time. The suitability of these X-ray parameters shall be demonstrated by attainment of required penetrameter (IQI) sensitivity and compliance with all other requirements stipulated herein. Guide E 94 contains provisions concerning exposure calculations and charts for the use of X-ray sources.

6.1.2 *Gamma Radiation Sources* — Isotope sources, when used, shall be capable of demonstrating the required radiographic sensitivity.

6.2 *Film Holders and Cassettes* — Film holders and cassettes shall be light-tight and shall be handled properly to reduce the likelihood that they may be damaged. They may be flexible vinyl, plastic, or any durable material; or, they may be made from metallic materials. In the event that light leaks into the film holder and produces images on the film extending into the area of interest, the film shall be rejected. If the film holder exhibits light leaks, it shall be repaired before reuse or discarded. Film holders and cassettes should be routinely examined to minimize the likelihood of light leaks.

6.3 *Intensifying Screens:*

6.3.1 *Lead-Foil Screens:*

6.3.1.1 Intensifying screens of the lead-foil type are generally used for all production radiography. Lead-foil screens shall be of the same approximate area dimensions as the film being used and they shall be in direct contact with the film during exposure.

6.3.1.2 For X-ray voltages between 200 kV and 1 MeV, front and rear screen thicknesses shall be a minimum of 0.005 in. (0.127 mm) thick. Below 200 kV,

front screen thicknesses up to 0.005 in. and rear screen thicknesses of at least 0.005 in. should be used if they improve radiographic quality. For isotope and high-voltage X-radiography (greater than 1 MeV) increased thicknesses may be appropriate for improvements in radiographic quality and should be used accordingly. Intermediate screens (between multiloaded film) may be used if desired.

6.3.1.3 Sheet lead, with or without backing, used for screens should be visually examined for dust, dirt, oxidation, cracking or creasing, foreign material or other condition that could render undesirable nonrelevant images on the film.

6.3.2 *Fluorescent or Fluorometallic Screens:*

6.3.2.1 Fluorescent or fluorometallic screen may be used. However, they must be capable of demonstrating the required penetrameter (IQI) sensitivity.

6.3.2.2 *Screen Care* — All screens should be handled carefully to avoid dents, scratches, grease, or dirt on active surfaces. Screens that render false indications on radiographs shall be discarded or reworked to eliminate the artifact.

6.4 *Filters* — Filters shall be used whenever the contrast reductions caused by low-energy scattered radiation or the extent of undercut and edge burn-off occurring on production radiographs is of significant magnitude so as to cause failure to meet the quality level or radiographic coverage requirements stipulated by the job order or contract (see Guide E 94).

6.5 *Masking* — Masking material may be used, as necessary, to help reduce image degradation due to undercutting (see Guide E 94).

6.6 *Penetrameters (IQI)* — Unless otherwise specified by the applicable job order or contract, only those penetrameters that comply with the design and identification requirements specified in Practice E 747 or Practice E 1025 shall be used.

6.7 *Shims and Separate Blocks* — Shims or separate blocks made of the same or radiographically similar materials (as defined in Method E 1025) may be used to facilitate penetrameter positioning. There is no restriction on shim or separate block thickness provided the penetrameter and area-of-interest density tolerance requirements of 9.7.6.2 are met.

6.8 *Radiographic Location and Identification Markers* — Lead numbers and letters are used to designate the part number and location number. The size and thickness of the markers shall depend on the ability of the radiographic technique to image the markers on the radiograph. As a general rule, markers $^{1}/_{16}$ in. (1.58 mm) thick will suffice for most low energy (less than 1 MeV) X-ray and Iridium-192 radiography; for higher energy radiography it may be necessary to use markers that are $^{1}/_{8}$ in. (3.17 mm) or more thick.

6.9 *Radiographic Density Measurement Apparatus* — Either a transmission densitometer or a step-wedge comparison film shall be used for judging film density requirements. Step wedge comparison films or densitometer calibration, or both, shall be verified by comparison with a calibrated step-wedge film traceable to the National Institute of Standards and Technology.

7. Reagents and Materials

7.1 *Film Systems* — Only film systems having cognizant engineering organization (CEO) approval or meeting the requirements of Test Method E 1815 shall be used to meet the requirements of this test method.

8. Requirements

8.1 *Procedure Requirement* — Unless otherwise specified by the applicable job order or contract, radiographic examination shall be performed in accordance with a written procedure. Specific requirements regarding the preparation and approval of written procedures shall be dictated by a purchaser and supplier agreement. The procedure details should include at least those items stipulated in Appendix X1. In addition, a radiographic standard shooting sketch (RSS), Fig. X1.1, shall be prepared similar to that shown in Appendix X1 and shall be available for review during interpretation of the film.

8.2 *Radiographic Coverage* — Unless otherwise specified by a purchaser and supplier agreement, the extent of radiographic coverage shall be the maximum practical volume of the casting. Areas that require radiography shall be designated as illustrated in Figs. X1.2 and X1.3 of Appendix X1. When the shape or configuration of the casting is such that radiography is impractical, these areas shall be so designated on drawings or sketches that accompany the radiographs. Examples of casting geometries and configurations that may be considered impractical to radiograph are illustrated in Appendix X2.

8.3 *Radiographic Film Quality* — All radiographs shall be free of mechanical, chemical, handling-related, or other blemishes which could mask or be confused with the image of any discontinuity in the area of interest on the radiograph. If any doubt exists as to the true nature of an indication exhibited by the film, the radiograph shall be retaken or rejected.

8.4 *Radiographic Quality Level* — The applicable job order or contract shall dictate the requirements for radiographic quality level. (See Practice E 1025 or Practice E 747 for guidance in selection of quality level.)

8.5 *Acceptance Level* — Radiographic acceptance levels and associated severity levels shall be stipulated by the applicable contract, job order, drawing, or other purchaser and supplier agreement.

8.6 *Radiographic Density Limitations* — Radiographic density in the area of interest shall be within 1.5 to 4.0 for either single or superimposed viewing.

8.7 *Film Handling:*

8.7.1 *Darkroom Facilities* — Darkroom facilities should be kept clean and as dust-free as practical. Safelights should be those recommended by film manufacturers for the radiographic materials used and should be positioned in accordance with the manufacturer's recommendations. All darkroom equipment and materials should be capable of producing radiographs that are suitable for interpretation.

8.7.2 *Film Processing* — Radiographic film processing shall be controlled in accordance with Guide E 999.

8.7.3 *Film Viewing Facilities* — Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflections, shadows, or glare on the radiograph. The viewing light shall be of sufficient intensity to review densities up to 4.0 and be appropriately controlled so that the optimum intensity for single or superimposed viewing of radiographs may be selected.

8.7.4 *Storage of Radiographs* — When storage is required by the applicable job order or contract, the radiographs should be stored in an area with sufficient environmental control to preclude image deterioration or other damage. The radiograph storage duration and location after casting delivery shall be as agreed upon between purchaser and supplier. (See Guide E 1254 for storage information.)

9. Procedure

9.1 *Time of Examination* — Unless otherwise specified by the applicable job order or contract, radiography may be performed prior to heat treatment and in the as-cast, rough-machined, or finished-machined condition.

9.1.1 *Penetrameter (IQI) Selection* — Unless otherwise specified in the applicable job order or contract, penetrameter (IQI) selection shall be based on the following: if the thickness to be radiographed exceeds the design thickness of the finished piece, the penetrameter (IQI) size shall be based on a thickness which does not exceed the design thickness of the finished piece by more than 20% or $\frac{1}{4}$ in. (6.35 mm), whichever is greater. In no case shall the penetrameter (IQI) size be based on a thickness greater than the thickness to be radiographed.

9.2 *Surface Preparation* — The casting surfaces shall be prepared as necessary to remove any conditions that could mask or be confused with internal casting discontinuities.

9.3 *Source-to-Film Distance* — Unless otherwise specified in the applicable job order or contract, geometric unsharpness (Ug) shall not be greater than one percent of the maximum part thickness being interpreted on the radiograph, or 0.070 in. (1.8 mm), whichever is less. Geometric unsharpness values shall be determined as specified in Guide E 94.

9.4 *Direction of Radiation* — The direction of radiation shall be governed by the geometry of the casting and the radiographic coverage and quality requirements stipulated by the applicable job order or contract. Whenever practicable, place the central beam of the radiation perpendicular to the surface of the film. Appendix X2 provides examples of preferred source and film orientations and examples of casting geometries and configurations on which radiography is impractical or very difficult.

9.5 *Back-Scattered Radiation Protection:*

9.5.1 *Back-Scattered Radiation* — (secondary radiation emanating from surfaces behind the film, that is, walls, floors, etc.) serves to reduce radiographic contrast and may produce undesirable effects on radiographic quality. A $\frac{1}{8}$-in. (3.17 mm) lead sheet placed behind the film generally furnishes adequate protection against back-scattered radiation.

9.5.2 To detect back-scattered radiation, position a lead letter "B" [approximately $\frac{1}{8}$ in. (3.17 mm) thick by $\frac{1}{2}$-in. (12.7 mm) high] on the rear side of the film holder. If a light image (lower density) of the lead letter "B" appears on the radiograph, it indicates that more back-scatter protection is necessary. The appearance of a dark image of the lead letter "B" should be disregarded unless the dark image could mask or be confused with rejectable casting defects.

9.6 *Penetrameter (IQI) Placement* — Place all penetrameters (IQI) being radiographed on the source side of the casting. Place penetrameters (IQI's) in the radiographic area of interest, unless the use of a shim or separate block is necessary, as specified in 9.7.6.

9.7 *Number of Penetrameters (IQI's):*

9.7.1 One penetrameter (IQI) shall represent an area within which radiographic densities do not vary more than +30% to −15% from the density measured through the body of the penetrameter (IQI).

9.7.2 When the film density varies more than −15% to +30%, two penetrameters (IQIs) used as follows will be acceptable: if one penetrameter (IQI) shows acceptable sensitivity representing the most dense portion of the exposure, and the second penetrameter (IQI) shows acceptable sensitivity representing the least dense portion of the exposure, then these two penetrameters (IQIs) shall qualify the exposure location within these densities, provided the density requirements stipulated in 8.6 are met.

9.7.3 For cylindrical or flat castings where more than one film holder is used for an exposure, at least one penetrameter (IQI) image shall appear on each radiograph. For cylindrical shapes, where a panoramic type source of radiation is placed in the center of the cylinder and a complete or partial circumference is radiographed using at least four overlapped film holders, at least three penetrameters (IQIs) shall be used. On partial circumference exposures, a penetrameter (IQI) shall be placed at each end of the length of the image to be evaluated on the radiograph with the intermediate penetrameters (IQIs) placed at equal divisions of the length covered. For full circumferential coverage, three penetrameters (IQIs) spaced 120° apart shall be used, even when using a single length of roll film.

9.7.4 When an array of individual castings in a circle is radiographed, the requirements of 9.7.1 or 9.7.2, or both, shall prevail for each casting.

9.7.5 If the required penetrameter (IQI) sensitivity does not show on any one film in a multiple film technique (see 9.11), but does show in composite (superimposed) film viewing, interpretation shall be permitted only by composite film viewing for the respective area.

9.7.6 When it is not practicable to place the penetrameter(s) (IQI) on the casting, a shim or separate block conforming to the requirements of 6.7 may be used.

9.7.6.1 The penetrameter (IQI) shall be no closer to the film than the source side of that part of the casting being radiographed in the current view.

9.7.6.2 The radiographic density measured adjacent to the penetrameter (IQI) through the body of the shim or separate block shall not exceed the density measured in the area of interest by more than 15%. The density may be lighter than the area of interest density, provided acceptable quality level is obtained and the density requirements of 8.6 are met.

9.7.6.3 The shim or separate block shall be placed at the corner of the film holder or close to that part of the area of interest that is furthest from the central beam. This is the worst case position from a beam angle standpoint that a discontinuity would be in.

9.7.6.4 The shim or separate block dimensions shall exceed the penetrameter (IQI) dimensions such that the outline of at least three sides of the penetrameter (IQI) image shall be visible on the radiograph.

9.7.7 *Film Side Penetrameter (IQI)* — In the case where the penetrameter (IQI) cannot be physically placed on the source side and the use of a separate block technique is not practical, penetrameters (IQI's) placed on the film side may be used. The applicable job order or contract shall dictate the requirements for film side radiographic quality level (see 8.4).

9.8 *Location Markers* — The radiographic image of the location markers for the coordination of the casting with the film shall appear on the film, without interfering with the interpretation, in such an arrangement that it is evident that the required coverage was obtained. These marker positions shall be marked on the casting and the position of the markers shall be maintained on the part during the complete radiographic cycle. The RSS shall show all marker locations.

9.9 *Radiographic Identification* — A system of positive identification of the film shall be provided. As a minimum, the following shall appear on the radiograph: the name or symbol of the examining laboratory, the date, the casting identification number, and whether it is an original or subsequent exposure.

9.10 *Subsequent Exposure Identification* — All repair radiographs after the original (initial) shall have an examination status designation that indicates the reason. Subsequent radiographs made by reason of a repaired area shall be identified with the letter "R" followed by the respective repair cycle (that is, R-1 for the first repair, R-2 for the second repair, etc.). Subsequent radiographs that are necessary as a result of additional surface preparation should be identified by the letters "REG."

9.11 *Multiple Film Techniques* — Two or more films of equal or different speeds in the same cassette are allowed, provided prescribed quality level and density requirements are met (see 9.7.2 and 9.7.5).

9.12 *Radiographic Techniques:*

9.12.1 *Single Wall Technique* — Except as provided in 9.12.2, radiography shall be performed using a technique in which the radiation passes through only one wall.

9.12.2 *Double Wall Technique* — For castings with an inside diameter of 4 in. or less, a technique may be

used in which the radiation passes through both walls and both walls are viewed for acceptance on the same film. An adequate number of exposures shall be taken to ensure that required coverage has been obtained.

9.13 *Safety* — Radiographic procedures shall comply with applicable city, state, and federal regulations.

10. Radiograph Evaluation

10.1 *Film Quality* — Verify that the radiograph meets the quality requirements specified in 8.3, 8.4, 8.6, 9.5.2 and 9.7.

10.2 *Film Evaluation* — Determine the acceptance or rejection of the casting by comparing the radiographic image to the agreed upon acceptance criteria (see 8.5).

11. Reference Radiographs

11.1 *Reference Radiographs* — E 155, E 186, E 192, E 272, E 280, E 310, E 446, E 505, E 689, and E 802 are graded radiographic illustrations of various casting discontinuities. These reference radiographs may be used to help establish acceptance criteria and may also be useful as radiographic interpretation training aids.

12. Report

12.1 The following radiographic records shall be maintained as agreed upon between purchaser and supplier:

12.1.1 Radiographic standard shooting sketch,

12.1.2 Weld repair documentation,

12.1.3 Film,

12.1.4 Film interpretation record containing as a minimum:

12.1.4.1 Disposition of each radiograph (acceptable or rejectable),

12.1.4.2 If rejectable, cause for rejection (shrink, gas, etc.),

12.1.4.3 Surface indication verified by visual examination (mold, marks, etc.), and

12.1.4.4 Signature of the film interpreter.

13. Precision and Bias

13.1 No statement has been made about either the precision or bias of this test method since the result merely states whether there is conformance to the criteria for success specified in the procedure.

14. Keywords

14.1 castings; gamma-ray; nondestructive testing; radiographic; radiography; X-ray

APPENDIXES

(Nonmandatory Information)

X1. RADIOGRAPHIC STANDARD SHOOTING SKETCH (RSS)

X1.1 The radiographic standard shooting sketch (RSS) provides the radiographic operator and the radiographic interpreter with pertinent information regarding the examination of a casting. The RSS is designed to standardize radiographic methodologies associated with casting examination; it may also provide a means of a purchaser and supplier agreement, prior to initiation of the examination on a production basis. The use of a RSS is advantageous due to the many configurations associated with castings and the corresponding variations in techniques for inspection of any particular one. The RSS provides a map of location marker placement, directions for source and film arrangement, and instructions for all other parameters associated with radiography of a casting. This information serves to provide the most efficient method for controlling the quality and consistency of the resultant radiographic representations.

X1.2 The RSS usually consists of an instruction sheet and sketch(es) of the casting: the instruction sheet specifies the radiographic equipment, materials, and technique-acceptance parameters for each location; the sketch(es) illustrate(s) the location, orientation, and the source and film arrangement for each location. Figs. X1.1-X1.3 of this appendix provide a typical instruction sheet and sketch sheets. As a minimum, the RSS should provide the following information. All spaces shall be filled in unless not applicable; in those cases, the space shall be marked NA.

X1.2.1 The instruction sheet should provide the following:

X1.2.1.1 Company preparing RSS and activity performing radiography.

X1.2.1.2 Casting identification including:

(a) Drawing number,

(b) Casting identification number,

(c) Descriptive name (for example, pump casting, valve body, etc.),

(d) Material type and material specification,

(e) Heat number, and

(f) Pattern number.

X1.2.1.3 Surface condition at time of radiography (as cast, rough machined, finished machined).

X1.2.1.4 Spaces for approval (as applicable).

X1.2.1.5 *Radiographic Technique Parameters for Each Location:*

(a) Radiographic location designation,

(b) Source type and size,

(c) Finished thickness,

(d) Thickness when radiographed,

(e) Penetrameters,

(f) Source to film distance,

(g) Film type and quantity,

(h) Film size,

(i) Required penetrameter (IQI) quality level,

(j) Radiographic acceptance standard, and

(k) Applicable radiographic severity level.

X1.2.2 The sketch(es) should provide the following:

X1.2.2.1 Location marker placement.

X1.2.2.2 Location of foundry's identification pad or symbol on the casting.

X1.2.2.3 Designation of areas that require radiography (as applicable).

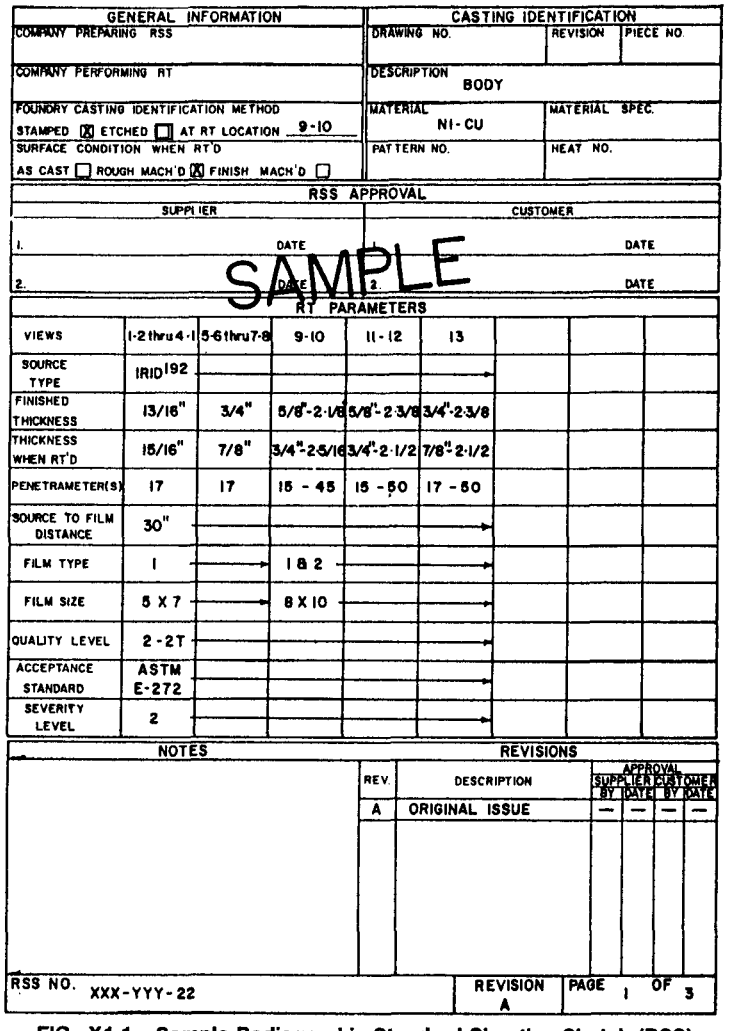
X1.2.2.4 Designation of areas that are considered impractical or very difficult to radiograph (see 1.2 and 8.2).

X1.2.2.5 Radiographic source and film arrangement and radiation beam direction for each location.

NOTE X1.1 — The RSS should designate the involved locations and stipulate that the technique for those locations is typical, for sections of the casting on which a continuing series of locations are to be radiographed with the same basic source and film arrangement for each location.

X1.2.3 Fig. X1.1 of this appendix provides a sample RSS that has been developed for a typical production application, and Figs. X1.2 and X1.3 provide sample RSS sketches that have been developed for a typical production application.

X1.2.4 The RSS may not provide what is considered to be the most effective means of technique control for all radiographic activities, but, in any event, some means of technique standardization should be employed. As a general rule, it is a beneficial practice for the supplier to solicit purchaser approval of the radiographic methodology prior to performing production radiography. This



GENERAL INFORMATION

COMPANY PREPARING RSS	
COMPANY PERFORMING RT	
FOUNDRY CASTING IDENTIFICATION METHOD	STAMPED [X] ETCHED [ ] AT RT LOCATION 9-10
SURFACE CONDITION WHEN RT'D	AS CAST [ ] ROUGH MACH'D [X] FINISH MACH'D [ ]

CASTING IDENTIFICATION

DRAWING NO.	REVISION	PIECE NO.
DESCRIPTION: BODY		
MATERIAL: NI-CU	MATERIAL SPEC.	
PATTERN NO.	HEAT NO.	

RSS APPROVAL

SUPPLIER	CUSTOMER
1. DATE	1. DATE
2. DATE	2. DATE

SAMPLE

RT PARAMETERS

VIEWS	1-2 thru 4-1	5-6 thru 7-8	9-10	11-12	13			
SOURCE TYPE	IRID 192	→	→	→	→			
FINISHED THICKNESS	13/16"	3/4"	5/8"-2-1/8	5/8"-2-3/8	3/4"-2-3/8			
THICKNESS WHEN RT'D	15/16"	7/8"	3/4"-2-5/16	3/4"-2-1/2	7/8"-2-1/2			
PENETRAMETER(S)	17	17	15 - 45	15 - 50	17 - 50			
SOURCE TO FILM DISTANCE	30"	→	→	→	→			
FILM TYPE	1	→	1 & 2	→	→			
FILM SIZE	5 X 7	→	8 X 10	→	→			
QUALITY LEVEL	2-2T	→	→	→	→			
ACCEPTANCE STANDARD	ASTM E-272	→	→	→	→			
SEVERITY LEVEL	2	→	→	→	→			

NOTES

REVISIONS

REV.	DESCRIPTION	APPROVAL SUPPLIER BY	SUPPLIER DATE	CUSTOMER BY	CUSTOMER DATE
A	ORIGINAL ISSUE	—	—	—	—

RSS NO. XXX-YYY-22 | REVISION A | PAGE 1 OF 3

FIG. X1.1 Sample Radiographic Standard Shooting Sketch (RSS)

FIG. X1.1 SAMPLE RADIOGRAPHIC STANDARD SHOOTING SKETCH (RSS)

generally entails the demonstration of the adequacy of the methodology by submitting the proposed technique parameters and a corresponding set of pilot radiographs to the purchaser for review. Purchaser approval of the technique shall be addressed in the applicable job order or contract.

X2. PREFERRED SOURCE AND FILM ALIGNMENT FOR FLANGE RADIOGRAPHY AND EXAMPLES OF AREAS THAT ARE CONSIDERED IMPRACTICAL TO RADIOGRAPH

X2.1 *Preferred Source and Film Alignment for Flange Radiography* — The effective use of radiography for assessing material soundness in casting areas where a flange joins a body is somewhat limited by the source and film alignment that the geometric configuration of these areas require. The following figures describe source and film alignments that can be employed and discusses the limits and benefits of each.

X3. EXAMPLES OF AREAS THAT ARE CONSIDERED TO BE IMPRACTICAL TO RADIOGRAPH

X3.1 Certain casting geometry configuration are inaccessible for conventional source and film arrangements that will provide meaningful radiographic results. These areas generally involve the juncture of two casting sections. The following illustrations provide typical examples of such areas.

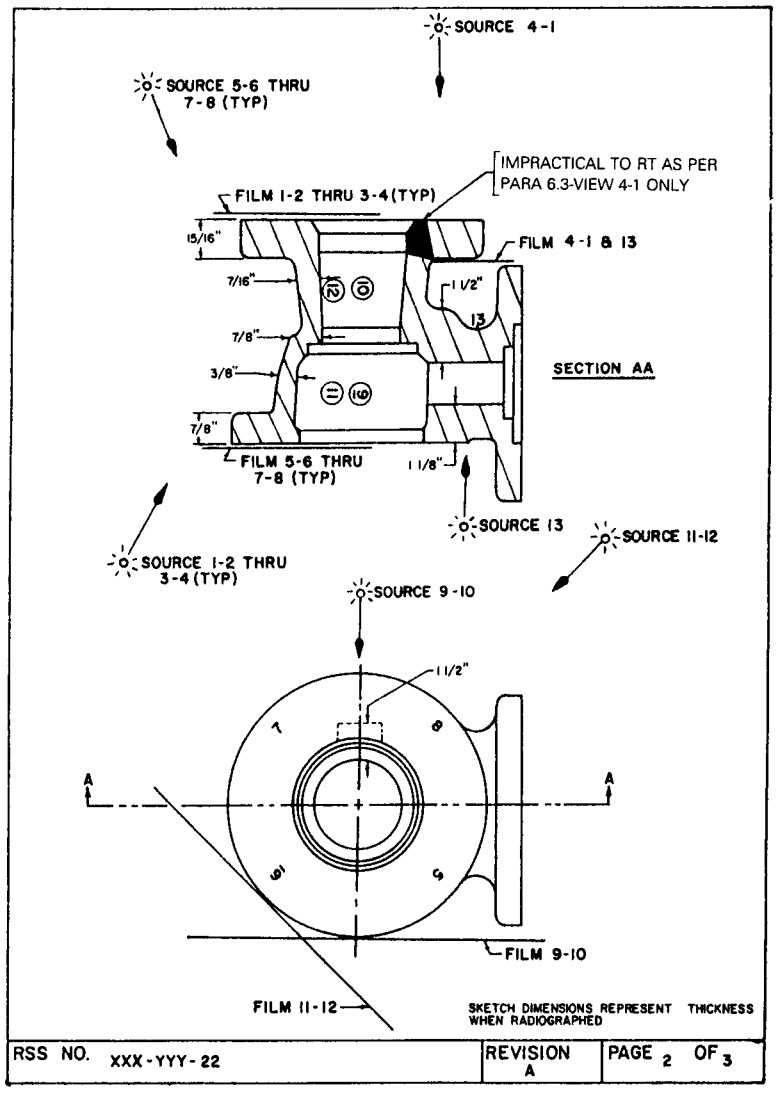


FIG. X1.2 SAMPLES OF RADIOGRAPHIC STANDARD SHOOTING SKETCHES (RSS)
VIEWS ILLUSTRATING LAYOUT AND SOURCE AND FILM PLACEMENT

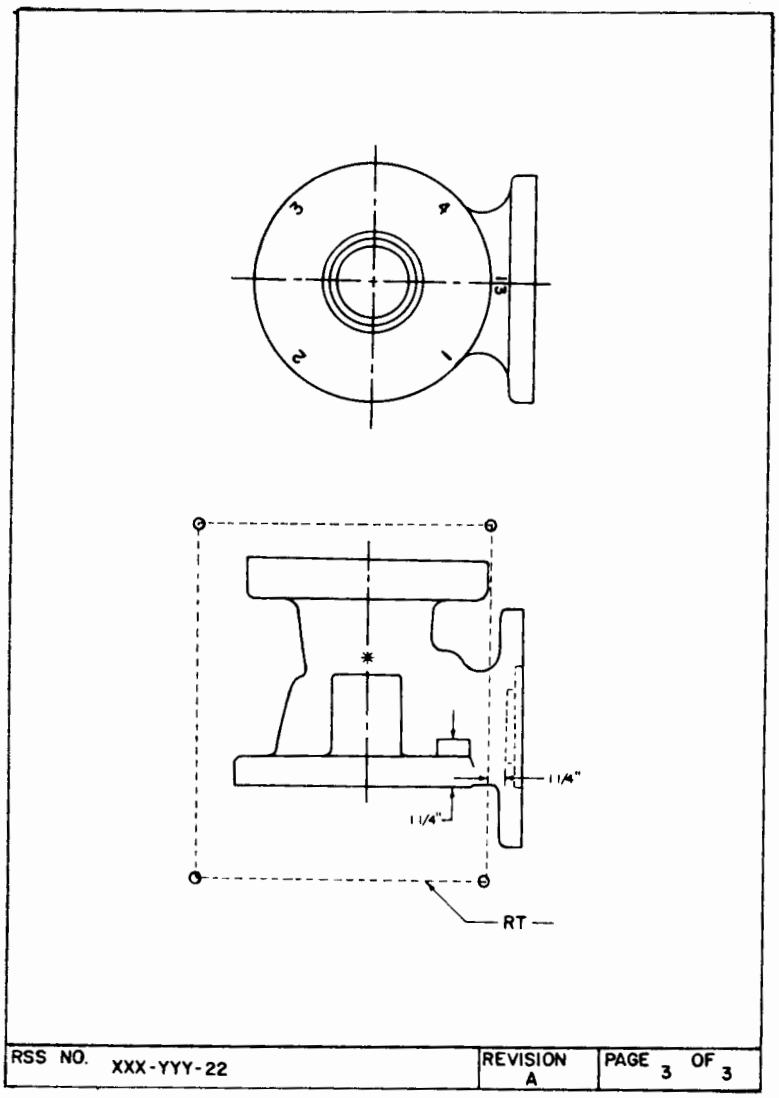
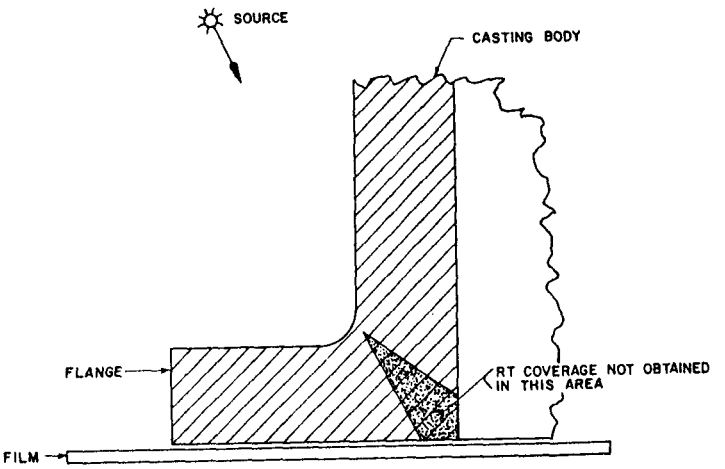
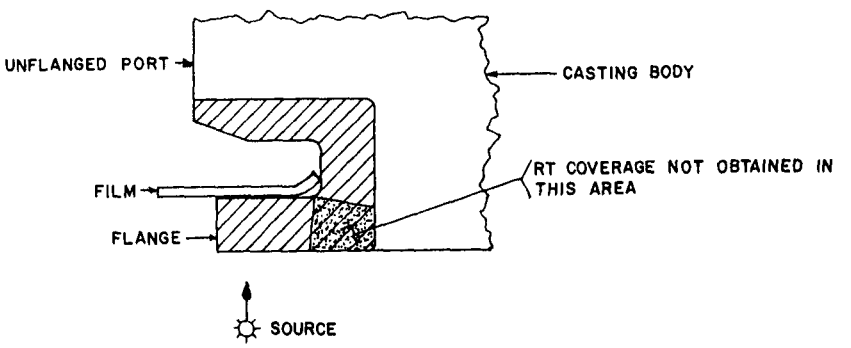


FIG. X1.3 SAMPLES OF RADIOGRAPHIC STANDARD SHOOTING SKETCHES (RSS)
VIEWS ILLUSTRATING LAYOUT AND EXTENT OF COVERAGE



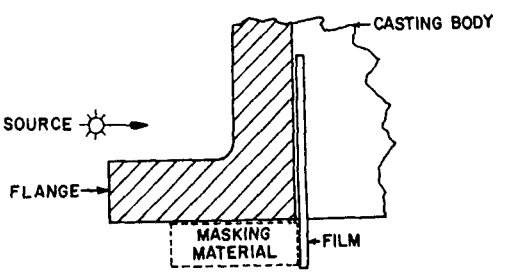
NOTE—For general application, this alignment provides the most effective compromise of quality radiography and maximum obtainable coverage.

FIG. X2.1 PREFERRED SOURCE AND FILM ALIGNMENT



NOTE—This alignment provides a suitable alternative when other casting appendages (bosses, flanges, etc.) project into the radiation path as illustrated in Fig. X2.2 when this alignment is used, additional losses in coverage (as opposed to Fig. X2.1) should be expected and noted accordingly on the applicable RSS.

FIG. X2.2 PERMISSIBLE SOURCE AND FILM ALIGNMENT WHEN FIG. X2.1 CANNOT BE APPLIED DUE TO CASTING GEOMETRY



NOTE—This alignment is permissible if the radiation source energy and film multi-load capabilities are sufficient to afford compliance with the technique requirements stipulated herein. This alignment will generally require the use of filters or masking to reduce the influence of radiation that undercuts the thicker areas and reduces overall radiographic quality.

FIG. X2.3 ALLOWABLE SOURCE FILM ALIGNMENT AS GOVERNED BY SOURCE ENERGY AND MULTI-FILM LOAD ACCEPTANCE DENSITY LATITUDE

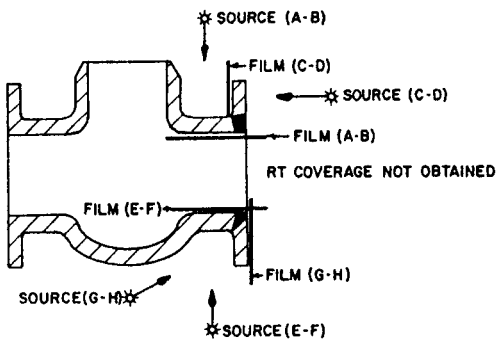


FIG. X3.1 AREAS INVOLVING FLANGES

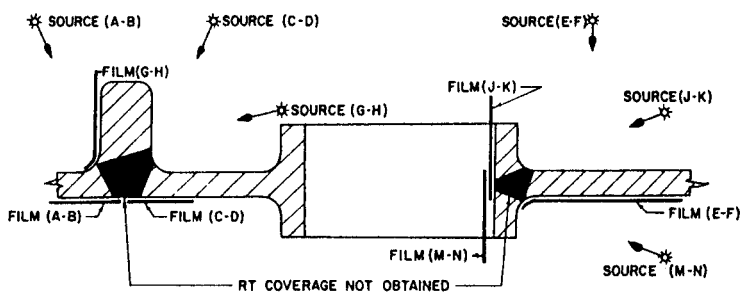


FIG. X3.2 AREAS INVOLVING OTHER JUNCTURES

A06

STANDARD TEST METHOD FOR DETERMINING THE FOCAL SIZE OF IRIDIUM-192 INDUSTRIAL RADIOGRAPHIC SOURCES

SE-1114

(Identical with ASTM Specification E 1114-03.)

1. Scope

1.1 This test method covers the determination of the focal size of an iridium-192 radiographic source. The determination is based upon measurement of the image of the iridium metal source in a projection radiograph of the source assembly and comparison to the measurement of the image of a reference sample in the same radiograph.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

E 1316 Terminology for Nondestructive Testing

E 1815 Test Method for Classification of Film Systems for Industrial Radiography

3. Terminology

3.1 For definitions of terms relating to this test method, refer to Terminology E 1316.

4. Significance and Use

4.1 One of the factors affecting the quality of a radiographic image is geometric unsharpness. The degree of geometric unsharpness is dependent upon the focal size of the source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the film. This test method allows the user to determine the focal size of the source and to use this result to establish source to object and object to film distances appropriate for maintaining the desired degree of geometric unsharpness.

5. Apparatus

5.1 *Subject Iridium-192 Source,* the focal size of which is to be determined. The appropriate apparatus and equipment for the safe storage, handling, and manipulation of the subject source, such as a radiographic exposure device (also referred to as a gamma ray projector or camera), remote control, source guide tube, and source stop are also required.

5.2 *Reference Sample (see Figs. 1,2, and 3)* — The reference sample shall be of material which is not radioactive. The recommended material is iridium. However, substitutes such as platinum, tungsten, or other material of similar radiopacity may be used. The sample should be of the same geometric shape as the subject source, should be approximately the same size as the subject source, and should be positioned on or within a shim or envelope to simulate the source capsule wall. The resulting radiographic contrast, with reference to adjacent background density of the image of the reference sample, should be approximately the same as that of the subject source. The actual dimensions of the reference sample should be determined to the nearest 0.025 mm (0.001 in.).

5.3 *X-ray Generator,* capable of producing a radiation intensity (roentgen per hour at one metre) at least ten

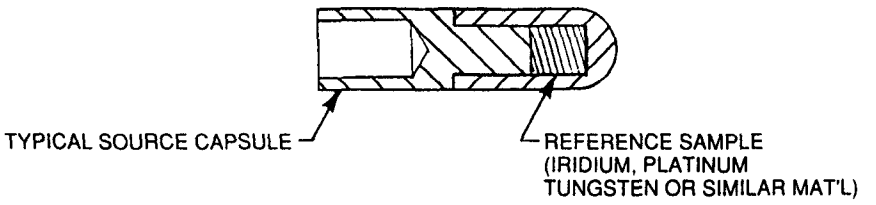
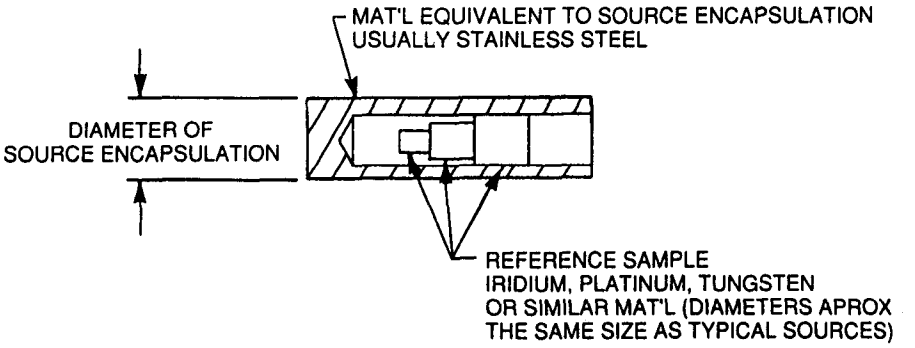


FIG. 1 REFERENCE SAMPLE IN STANDARD SOURCE ENCAPSULATION



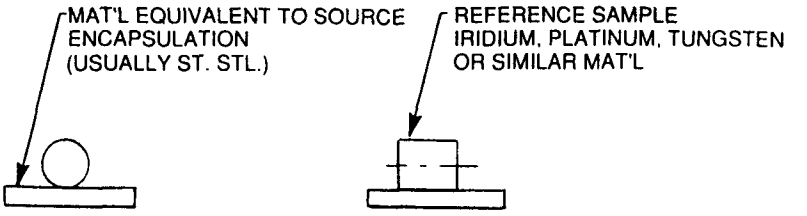


FIG. 2 ALTERNATE REFERENCE SAMPLE ARRANGEMENT

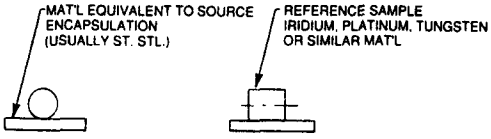


FIG. 3 ALTERNATE REFERENCE SAMPLE ARRANGEMENT

times greater than that produced by the subject source. Examples of typical X-ray generator output requirements that satisfy this criterion are presented in Table 1.

5.4 *Film Systems* — Only film systems having cognizant engineering organization approval or meeting the system class requirements of Test Method E 1815, for system classes I, II, or Special, shall be used. Selection of film systems should be determined by such factors as the required radiographic quality level, equipment capability, materials, and so forth. The film system selected shall be capable of demonstrating the required image quality. No intensifying screens should be used. Radiographic films shall be processed in accordance with Guide E 999.

5.5 *Image Measurement Apparatus* — This apparatus is used to measure the size of the image of the focal spot.

TABLE 1
EXAMPLES OF TYPICAL X-RAY GENERATOR OUTPUT REQUIREMENTS FOR RELATED IRIDIUM^{192} SOURCE ACTIVITIES

Subject Iridium^{192} Source Radiation			Typical X-ray Generator Output Requirements	
Activity (Curie)	Output (Rh at 1 m)		Potential	Current
30	14.4		160 kV	5 mA
		or	200 kV	3 mA
100	48.0		160 kV	10 mA
		or	250 kV	4 mA
200	96.0		160 kV	20 mA
		or	250 kV	8 mA
		or	300 kV	6 mA

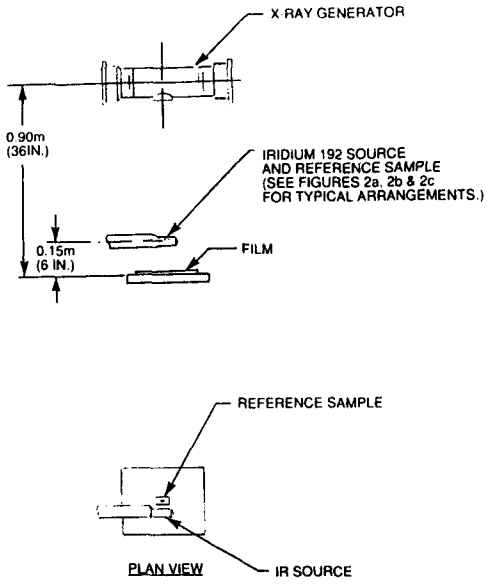


FIG. 4 TYPICAL EXPOSURE ARRANGEMENT

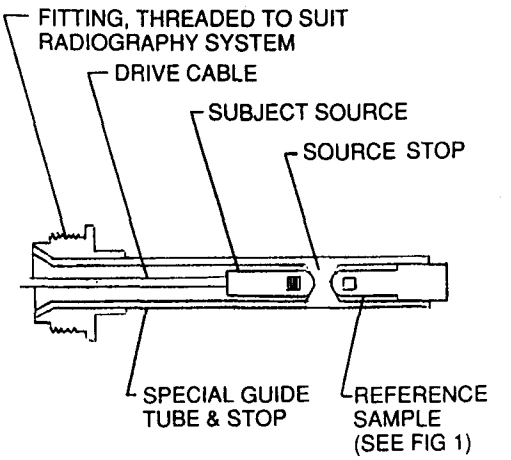


FIG. 5 TYPICAL ARRANGEMENT USING A SPECIALLY DESIGNED GUIDE TUBE

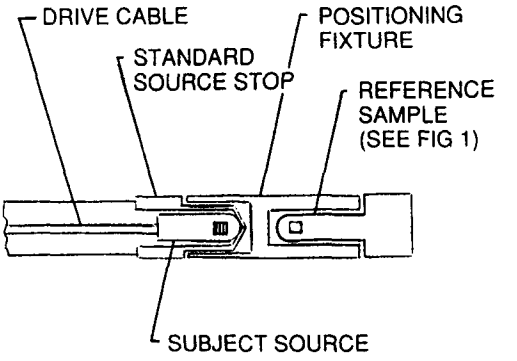


FIG. 6 TYPICAL ARRANGEMENT USING A STANDARD GUIDE TUBE AND SPECIAL POSITIONING FIXTURE

The apparatus shall be an optical comparator with built-in graticule with 0.1 mm divisions or 0.001 in. divisions and magnification of 5× to 10×.

6. Procedure

6.1 Set up the exposure arrangement as shown in Figs. 4, 5, 6, and 7. Position the X-ray tube directly over the center of the film. The film plane must be normal to the central ray of the X-ray beam. The X-ray focal spot should be 0.90 m (36 in.) from the film. Position the reference sample and apparatus used to locate the subject source (source stop) as close together as possible and directly over the center of the film. The plane of the source stop and reference sample must be parallel to the film and normal to the central ray of the X-ray beam. The source stop and reference sample should be 0.15 m (6 in.) from the film. The source stop should be connected to the radiographic exposure device by the shortest source guide tube practicable in order to minimize fogging of the film during source transit.

6.2 Place identification markers to be imaged on the film to identify, as a minimum, the identification (serial number) of the subject source, the size of the reference sample, the identification of the organization performing the determination, and the date of the determination. Care should be taken to ensure that the images of the subject source and reference sample will not be superimposed on the image of the identification markers.

6.3 *Exposure* — Select the X-ray tube potential (kV), X-ray tube current (mA), and exposure time such that

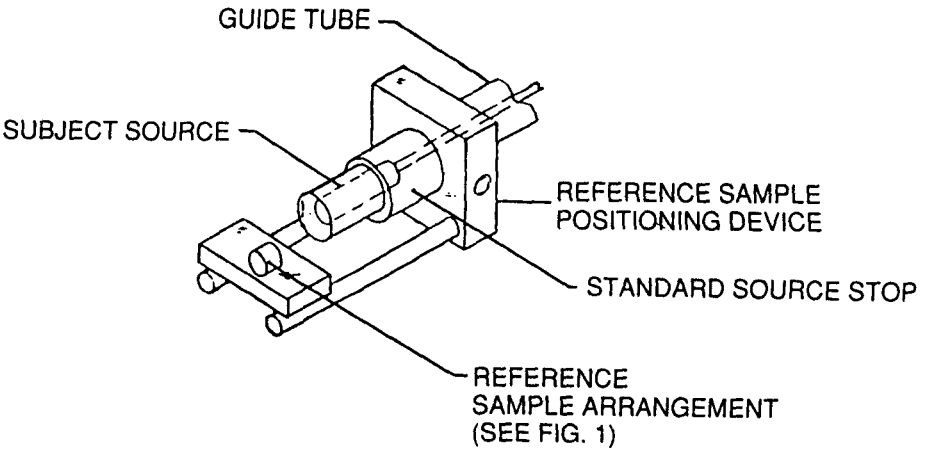


FIG. 7 TYPICAL ARRANGEMENT USING REFERENCE SAMPLE POSITIONING DEVICE

the density in the image of the envelope surrounding the reference sample does not exceed 3.0 and that the density difference between the image of the reference sample and the image of the envelope surrounding the reference sample is at least 0.10.

NOTE — The actual parameters that will produce acceptable results may vary between X-ray units, and trial exposures may be necessary.

6.3.1 Energize the X-ray generator and, at the same time, manipulate the subject source into the exposure position in the source stop. It is important that this be performed as quickly as possible to minimize fogging of the film.

6.3.2 At the conclusion of the exposure time, deenergize the X-ray generator and, at the same time, return the subject source to the proper shielded storage position.

6.3.3 Process the film.

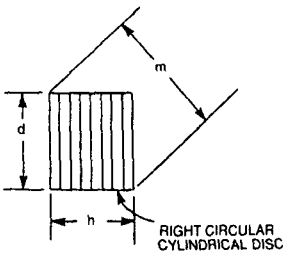


FIG. 8 UNIFORM RIGHT CIRCULAR CYLINDER

FIG. 9 SPHERE

7. Measurement of Focal Dimensions

7.1 View the radiograph with sufficient light intensity for adequate viewing. Using an optical comparator with built-in graticule as described in 5.5, measure the linear dimensions of the image of the focal spot of the subject source and the reference sample. Take measurements from the perceptible edges of the image. When performing the physical measurements with the optical comparator, the actual measured values shall be to the nearest graduation on the graticule scale being used.

7.2 The focal size for a given technique is the maximum projected dimension of the source in the plane perpendicular to a line drawn from the source to the object being radiographed. Therefore, sufficient measurements of the image of the iridium must be made to determine the focal size of the source in any orientation. Sections 7.2.1 through 7.2.4 serve as examples.

7.2.1 *Uniform Right Circular Cylinder* (see Fig. 8) — Determine the focal size of a uniform right circular cylindrical source by measuring the diameter, *d*, the height, *h*, and the diagonal, *m*, as illustrated in Fig. 8 and computing the actual dimensions as described in 8.1.

7.2.2 *Sphere* (see Fig. 9) — Determine the focal size of a spherical source by measuring the diameter, *d*, as illustrated in Fig. 9 and computing the actual dimension as described in 8.1.

7.2.3 *Nonuniform Stack of Right Circular Cylinders* (see Fig. 10) — Determine the focal size of a nonuniform stack of right circular cylindrical components of a source by measuring the intrinsic diameter, *d*, the height, *h*, and

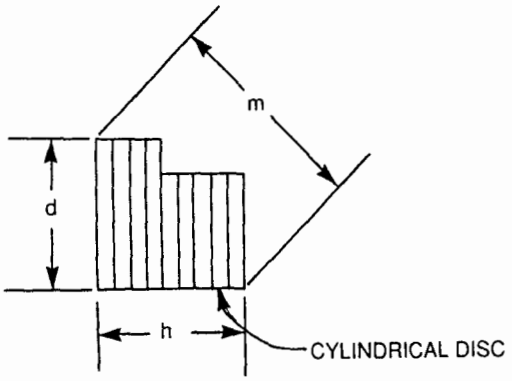


FIG. 10 NONUNIFORM CYLINDRICAL STACK

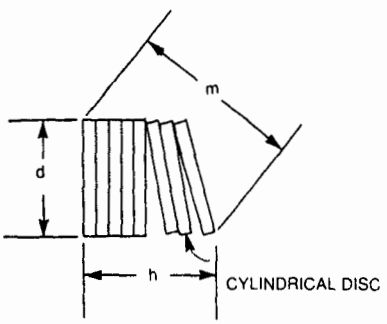


FIG. 11 SEPARATED CYLINDRICAL STACK

the effective maximum dimension, m, as illustrated in Fig. 10 and computing the actual dimensions as described in 8.1.

7.2.4 *Separated Stack of Right Circular Cylinders* (see Fig. 11) — Determine the focal size of a separated stack of right circular cylindrical components of a source by measuring the intrinsic diameter, d, the effective height, h, and the effective maximum dimension, m, as illustrated in Fig. 11 and computing the actual dimensions as described in 8.1.

8. Calculation and Evaluation

8.1 Measure the linear dimension of interest in the subject source image and measure the same linear dimension in the reference sample image (that is, the diameter of each). The actual dimension of the subject source is computed from the following:

$$a = \frac{bc}{d}$$

where:

a = actual dimension of the subject source,
b = actual dimension of the reference sample,
c = measured dimension of the subject source image, and
d = measured dimension of the reference sample image.

9. Report

9.1 A report of the focal size of an iridium-192 source should indicate the model number and serial number of the source, the name of the organization making the determination, the date the determination was made, a description of the shape of the source (or an appropriate sketch), and the calculated actual dimensions. The actual radiograph should accompany the report.

10. Keywords

10.1 cylinder(s); focal size; iridium 192; radiographic source; reference sample; sphere

STANDARD TEST METHOD FOR MEASUREMENT OF FOCAL SPOTS OF INDUSTRIAL X-RAY TUBES BY PINHOLE IMAGING

A06

SE-1165

(Identical with ASTM Specification E 1165-04.)

1. Scope

1.1 This test method provides instructions for determining the length and width dimensions of line focal spots in industrial X-ray tubes (see Note 1). This determination is based on the measurement of an image of a focal spot that has been radiographically recorded with a "pinhole" projection/imaging technique.

NOTE 1 — Line focal spots are associated with vacuum X-ray tubes whose maximum voltage rating does not generally exceed 500 kV.

1.2 This test method may not yield meaningful results on focal spots whose nominal size is less than 0.3 mm (0.011 in.). (See Note 2.)

NOTE 2 — The X-ray tube manufacturer may be contacted for nominal focal spot dimensions.

1.3 This test method may also be used to determine the presence or extent of focal spot damage or deterioration that may have occurred due to tube age, tube overloading, and the like. This would entail the production of a focal spot radiograph (with the pinhole method) and an evaluation of the resultant image for pitting, cracking, and the like.

1.4 Values stated in SI units are to be regarded as the standard. Inch-pound units are provided for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Document

2.1 *ASTM Standard:*

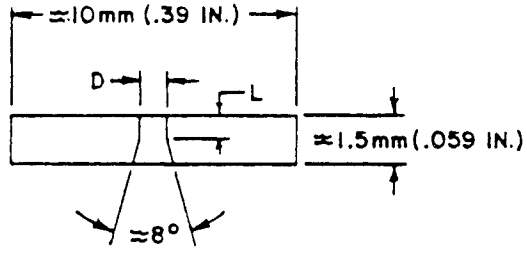


FIG. 1 PINHOLE DIAPHRAGM DESIGN

E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing

3. Terminology

3.1 *Definitions of Terms Specific to This Standard*

3.1.1 *actual focal spot* — the X-ray producing area of the target as viewed from a position perpendicular to the target surface (see Fig. 2).

3.1.2 *effective focal spot* — the X-ray producing area of the target as viewed from a position perpendicular to the tube axis in the center of the X-ray beam (see Fig. 2).

3.1.3 *line focal spot* — a focal spot whose projected pinhole image consists primarily of two curved lines (see Fig. 3).

4. Significance and Use

4.1 One of the factors affecting the quality of a radiographic image is geometric unsharpness. The degree of geometric unsharpness is dependent upon the focal size

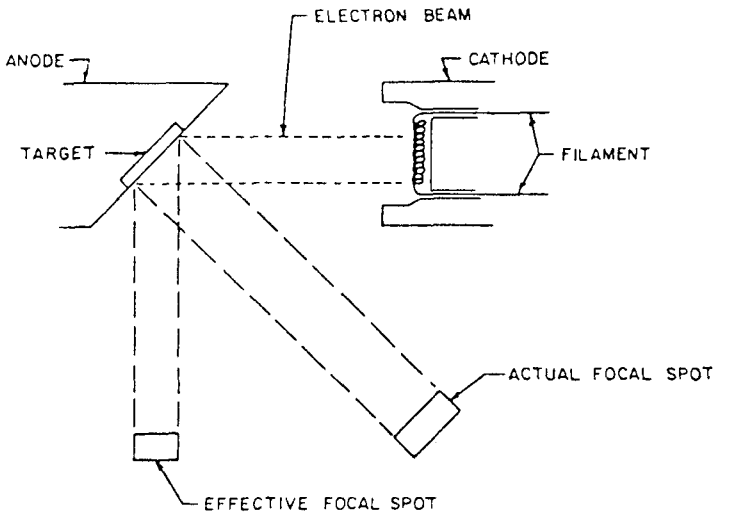
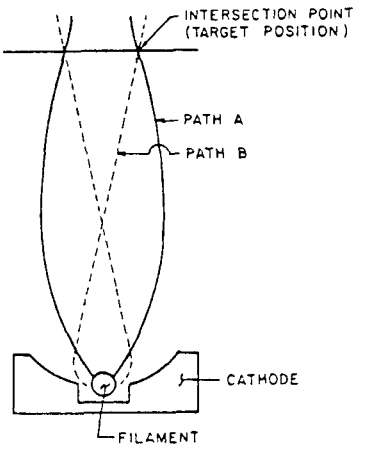
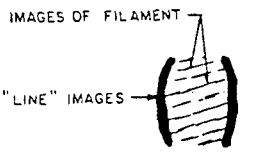


FIG. 2 ACTUAL/EFFECTIVE FOCAL SPOT



SKETCH 1



SKETCH 2

NOTE—During the production of X-rays the electrons are accelerated from the filament to the target in two separate paths (see Sketch 1). Electrons emitted at the front of the filament travel primarily along Path A, and electrons emitted at the backside of the filament travel primarily along Path B. Note that these two paths intersect at a certain point; this is the point at which the target is positioned. As a result, the pinhole picture of the focal spot shows two lines that correspond with the intersections of Paths A and B at the target (see Sketch 2).

FIG. 3 LINE FOCAL SPOT

of the radiation source, the distance between the source and the object to be radiographed, and the distance between the object to be radiographed and the film. This test method allows the user to determine the focal size of the X-ray source and to use this result to establish source to object and object to film distances appropriate for maintaining the desired degree of geometric unsharpness.

5. Apparatus

5.1 *Pinhole Diaphragm* — The pinhole diaphragm shall conform to the design and material requirements of Table 1 and Fig. 1.

5.2 *Camera* — The pinhole camera assembly consists of the pinhole diaphragm, the shielding material to which it is affixed, and any mechanism that is used to hold the

TABLE 1
PINHOLE DIAPHRAGM DESIGN REQUIREMENTS (DIMENSION)[A]

Nominal Dimension of Focal Spot, mm (in.)[B]	Nominal Diameter of Diaphragm Opening, mm (in.)	Required "D" and "L" Dimensions, mm (in.)	
		D	L
>0.3 to 1.2 (0.011 to 0.046) incl	0.030 (0.0011)	0.030 ± 0.005 (0.0011 ± 0.0002)	0.075 ± 0.010 (0.0029 ± 0.0004)
>1.2 to 2.5 (0.046 to 0.097) incl	0.075 (0.0029)	0.075 ± 0.005 (0.0029 ± 0.0002)	0.350 ± 0.010 (0.014 ± 0.0004)
>2.5 (0.097)	0.100 (0.0039)	0.100 ± 0.005 (0.0039 ± 0.0002)	0.500 ± 0.010 (0.02 ± 0.0004)

NOTE — The pinhole diaphragm shall be made from one of the following materials:
(1) An alloy of 90% gold and 10% platinum,
(2) Tungsten,
(3) Tungsten carbide,
(4) Tungsten alloy,
(5) Platinum and 10% Iridium alloy, or
(6) Tantalum.

[A] See Fig. 3.
[B] Nominal focal spot dimensions may be obtained from the X-ray tube manufacturer.

shield/diaphragm in position (jigs, fixtures, brackets, and the like; see Fig. 4).

5.3 *Film* — Industrial type extra fine grain. No intensifying screens are to be used. The film shall be processed in accordance with Guide E 999.

5.4 *Image Measurement Apparatus* — This apparatus is used to measure the size of the image of the focal spot. The apparatus shall be an optical comparator with built-in graticule with 0.1 mm or 0.001 in., or both divisions and magnification of 5× to 10× (or equivalent).

6. Procedure

6.1 If possible, use a standard 91.44 cm (36 in.) focal spot to film plane distance (FFD) for all exposures. If machine geometry or accessibility limitations will not permit the use of a 91.44 cm (36 in.) FFD, use the maximum attainable FFD (in these instances adjust the relative distances between focal spot, pinhole, and film accordingly to suit the image enlargement factors specified in Table 2). The distance between the focal spot and the pinhole is based on the nominal size of the focal spot being measured and the desired degree of image enlargement (see Fig. 5). The specified focal spot to pinhole distance (FHD) for the different nominal focal spot size ranges is provided in Table 2. Position the pinhole such that it is within ±1° of the central axis of the X-ray beam. Figure 6 illustrates a typical focal spot exposure arrangement.

NOTE 3 — The accuracy of the pinhole system is highly dependent upon the relative distances between (and alignment of) the focal spot, the pinhole, and the film. Accordingly, specially designed apparatus may be necessary in order to assure compliance with the above requirements. Figure 7 provides an example of a special collimator that can be used to ensure conformance with the ±1° alignment tolerance. Some other standards impose very stringent alignment requirements and express these requirements in terms of radial tolerances. These documents do not, however, address any means for assuring compliance with such tolerances. In order to simplify the focal spot radiography technique and to improve the overall practicality of the procedure, it is considered that a workable alignment tolerance, and a means of assuring conformance with that tolerance, is appropriate. Accordingly, this standard addresses tolerances in angular terms and provides a method for assuring compliance with these tolerances. This provides a practical means of meeting the precision and bias requirements of Section 9.

6.2 Position the film as illustrated in Fig. 6. The exposure identification appearing on the film (by radiographic imaging) should be X-ray machine identity (that is, make and serial number), organization making the radiograph, and date of exposure.

6.3 Adjust the kilovoltage and milliamperage settings on the X-ray machine to that specified in Table 3.

6.4 Expose the film such that the density of the darkest portion of the focal spot image conforms to the limits specified in Table 4. Density measurement shall be as illustrated in Fig. 8. Density shall be controlled by exposure time only.

6.5 Process the film in accordance with Guide E 999.

6.6 *Focal Spot Measurement:*

6.6.1 *Back Lighting* — Back lighting shall be such that the focal spot image can be easily and comfortably viewed.

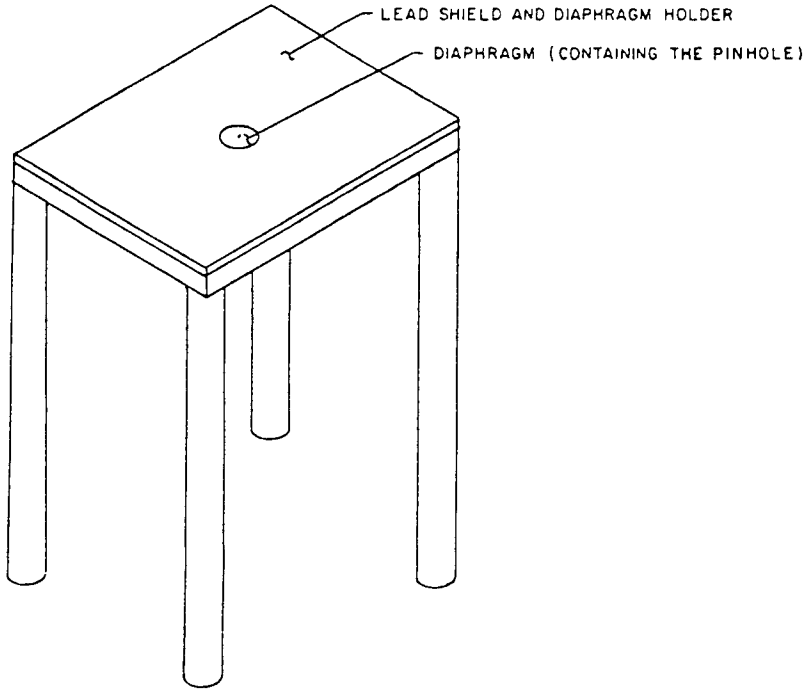


FIG. 4 PINHOLE CAMERA (TYPICAL)

TABLE 2
IMAGE ENLARGEMENT FACTORS

Nominal Focal Spot Size, mm (in.)	Enlargement Factor	Distance Between Focal Spot and Pinhole (FHD), cm (in.)[A]
0.3 to 1.2 (0.011 to 0.046) incl	3×	22.9 (9)
>1.2 to 2.5 (0.046 to 0.097) incl	2×	30.5 (12)
>2.5 (0.097)	1×	45.7 (18)

[A] When using a technique that entails the use of enlargement factors and a 91.44 cm (36 in.) focal spot to film distance (FFD) is not possible (see 6.1), the distance between the focal spot and the pinhole (FHD) shall be adjusted to suit the actual focal spot to film distance (FFD) used [for example, if a 61 cm (24 in.) FFD is used, the FHD shall be 15.25 cm (6 in.) for 3× enlargement, 20.32 cm (8 in.) for 2× enlargement, and the like].

6.6.2 Place the magnification graticule (handheld optical comparator) in intimate contact with the film for the measurement determination. Determine an imaginary "box" that represents the perceptible edges of the focal spot image [see Fig. 9(a)] for the extremities measurement.

6.6.3 Measure the focal spot image in two directions [see Fig. 9(b)]:

6.6.3.1 Direction A — Parallel to the axis of the tube.

6.6.3.2 Direction B — Perpendicular to the axis of the tube.

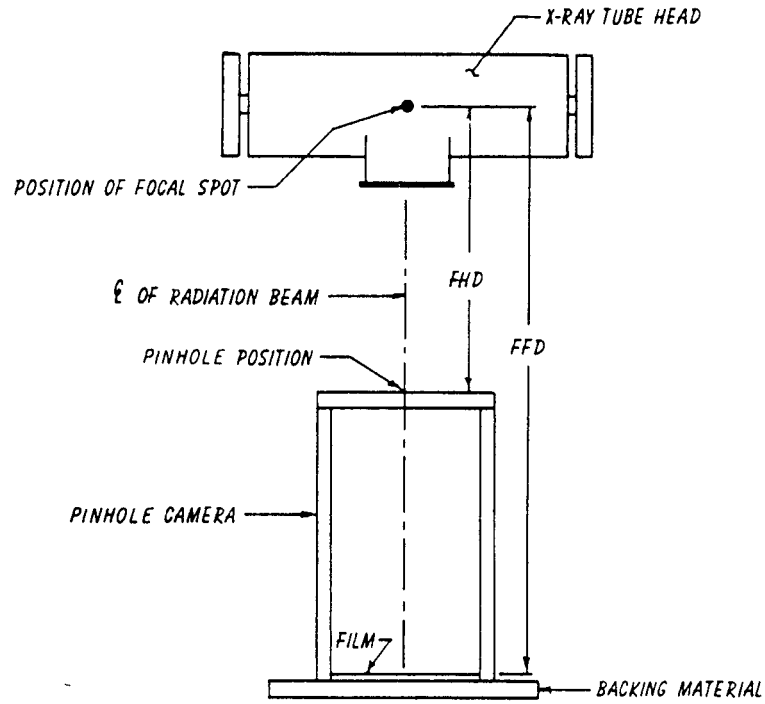
7. Calculation of Results

7.1 Multiply the measured "A" direction dimension by a correction factor of 0.7 to determine the actual "A" dimension (see Notes 4 and 5). The measured "B" direction dimension is representative of actual size.

NOTE 4 — The need for the 0.7 fractional multiplier for correction of the measured image length arises from the fact that the lengthwise distribution of energy in the focal spots of line-focus tubes tends to be peaked in the center and diminishes gradually to zero at the ends. Hence, the effective length, (that is, resultant effect on radiographic definition and film density distribution) cannot be stated as equal to the measured length.

NOTE 5 — European standard EN 12543-2 describes a similar x-ray focal spot measurement method (pin-hole method), but does not use the "0.7" correction factor described within this standard. EN 12543-2, at the time of this revision, has a range of applications considered beyond the scope of E 1165. International users of these standards should be aware of this difference for their particular applications.

7.2 If an image enlargement technique was used, divide the "A" and "B" direction measurements by the pertinent enlargement factor to obtain actual focal spot size (see Fig. 5 and Table 2).



FFD = 91.44 cm (36 in.)
FHD = 22.86 cm (9 in.) for 3X enlargement
30.48 cm (12 in.) for 2X enlargement
45.72 cm (18 in.) for 1X enlargment

NOTE—See 6.1 and Table 1 if a 91.44 cm (36 in.) FFD is not achievable.

FIG. 5 SCHEMATIC OF FHD/FFD RELATIONSHIP

8. Report

8.1 A report documenting the focal spot size determination should include the machine model number and serial number, the X-ray tube serial number, the focal spot(s) that was measured (some machines have dual focal spots), the set-up and exposure parameters (for example, kilovoltage, milliamps, enlargement factor, and the like) date, name of organization, and estimated beam time hours (if available).

9. Precision and Bias

9.1 Conformance to the requirements specified herein will produce results that are within the following tolerances:

9.1.1 *Technique* — The technique requirements specified herein will produce a focal spot image whose size is ±5% of the actual effective focal spot size.

9.1.2 *Measurement* — The measurement requirements specified herein will produce results that are within the tolerances:

Nominal Focal Spot Size, mm (in.)	Measurement Tolerances
0.3 to 1.2 (0.011 to 0.046) incl	±30%
>1.2 to 2.5 (0.046 to 0.097) incl	±25%
>2.5 (0.097)	±20%

10. Keywords

10.1 focal spots; pinhole camera; pinhole imaging; X-ray; X-ray tube

TABLE 3
TEST VOLTAGE AND CURRENT

kVp Rating of X-Ray Machine	Voltage To Be Used for Focal Spot Radiography	Current To Be Used for Focal Spot Radiography
≤75 kV	maximum rated voltage	
>75 kV to 150 kV	75 kV	50% of maximum permissible current at the test voltage utilized
>150 kV	50% of maximum rated voltage	

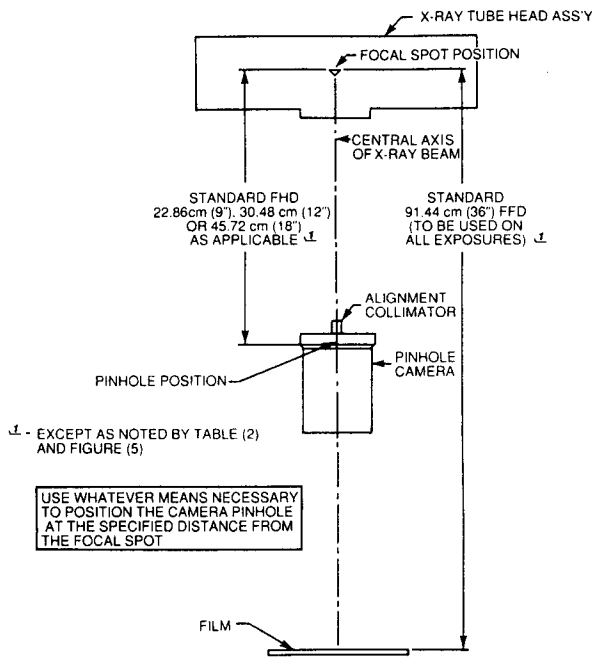


FIG. 6 EXPOSURE SET-UP SCHEMATIC

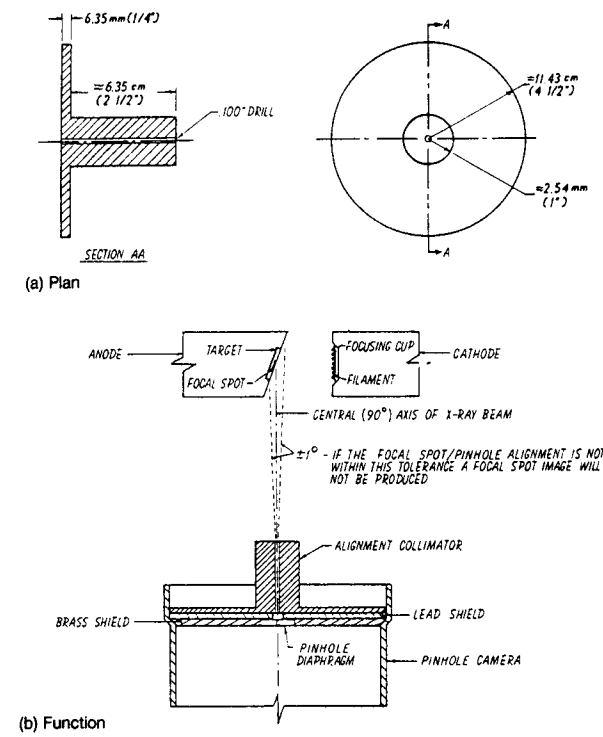
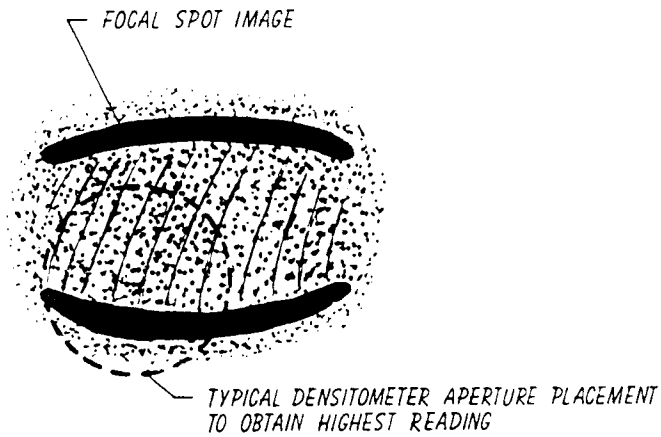


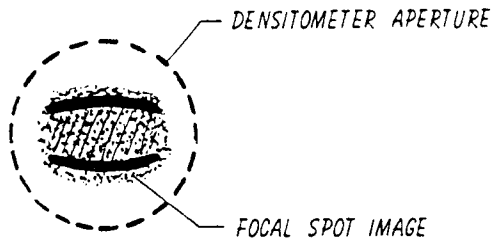
FIG. 7 ALIGNMENT COLLIMATOR

TABLE 4
DENSITY RANGE FOR DARKEST AREA OF FOCAL SPOT IMAGE (See Fig. 7)

Transmission Densitometer Aperture Diameter, mm (in.)	For images whose minimum dimension is less than 2 mm (0.078 in.)	For images whose minimum dimension is greater than 2 mm (0.078 in.)
1 (0.039)	0.8 to 2.0 density	1.0 to 3.0 density
2 (0.078)	0.5 to 1.8 density	1.0 to 3.6 density

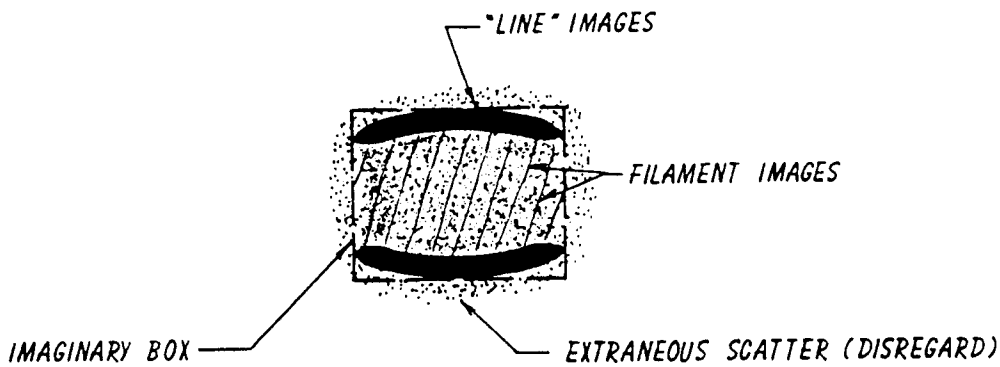


NOTE—For instances where the focal spot image is larger than the densitometer aperture, measure the density in several places to determine the darkest area.

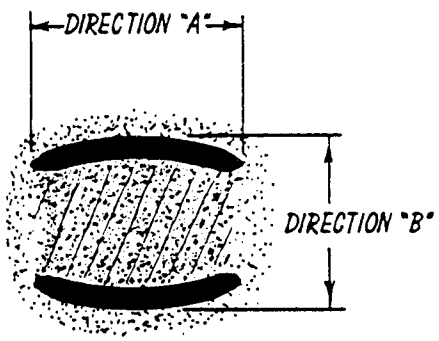


NOTE—For instances where the focal spot image is smaller than the densitometer aperture, center the focal spot image in the densitometer aperture area.

FIG. 8 FOCAL SPOT DENSITY MEASUREMENT



(a) Imaginary "Box" That Represents the Perceptible Edges of the Focal Spot Image



(b) Measurement Direction

FIG. 9 FOCAL SPOT IMAGE

STANDARD PRACTICE FOR RADIOSCOPY

SE-1255

(Identical with ASTM Specification E 1255-96)

1. Scope

1.1 This practice provides application details for radioscopic examination using penetrating radiation. This includes dynamic radioscopy and for the purposes of this practice, radioscopy where there is no motion of the test object during exposure (referred to as static radioscopic imaging). Since the techniques involved and the applications for radioscopic examination are diverse, this practice is not intended to be limiting or restrictive, but rather to address the general applications of the technology and thereby facilitate its use. Refer to Guides E 94 and E 1000, Terminology E 1316, Practice E 747, Practice E 1025, and Fed. Std. Nos. 21 CFR 1020.40 and 29 CFR 1910.96 for a list of documents that provide additional information and guidance.

1.2 The general principles discussed in this practice apply broadly to penetrating radiation radioscopic systems. However, this document is written specifically for use with X-ray and gamma-ray systems. Other radioscopic systems, such as those employing neutrons, will involve equipment and application details unique to such systems.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific safety statements, see Section 8 and Fed. Std. Nos. 21 CFR 1020.40 and 29 CFR 1910.96.

2. Referenced Documents

2.1 *ASTM Standards:*

E 94 Guide for Radiographic Testing

E 747 Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E 1000 Guide for Radioscopy

E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Federal Standards:*

21 CFR 1020.40 Safety Requirements of Cabinet X-Ray Systems

29 CFR 1910.96 Ionizing Radiation

2.4 *National Council on Radiation Protection and Measurement (NCRP) Standard:*

NCRP 49 Structural Shielding Design and Evaluation for Medical Use of X-Rays and Gamma Rays of Energies up to 10 MeV

3. Summary of Practice

3.1 Manual evaluation as well as computer-aided automated radioscopic examination systems are used in a wide variety of penetrating radiation examination applications. A simple manual evaluation radioscopic examination system might consist of a radiation source and a directly viewed fluorescent screen, suitably enclosed in a radiation protective enclosure. At the other extreme, a complex automated radioscopic examination system might consist of an X-ray source, a robotic test part manipulator, a radiation protective enclosure, an electronic image detection system, a closed-circuit television image transmission system, a digital image processor, a

video display, and a digital image archiving system. All system components are supervised by the host computer, which incorporates the software necessary to not only operate the system components, but to make accept/reject decisions as well. Systems having a wide range of capabilities between these extremes can be assembled using available components. Guide E 1000 lists many different system configurations.

3.2 This practice provides details for applying radioscopic examination techniques, however, supplemental requirements are necessary to address areas that are application and performance specific. Annexes A1 and A2 provide the detailed supplemental requirements for government contracts (Annex A1) and nongovernment contracts (Annex A2).

4. Significance and Use

4.1 As with conventional radiography, radioscopic examination is broadly applicable to any material or test object through which a beam of penetrating radiation may be passed and detected including metals, plastics, ceramics, composite, and other nonmetallic materials. In addition to the benefits normally associated with radiography, radioscopic examination may be either a dynamic, filmless technique allowing the test part to be manipulated and imaging parameters optimized while the test object is undergoing examination, or a static, filmless technique wherein the test part is stationary with respect to the X-ray beam. Recent technology advances in the area of projection imaging, detectors, and digital image processing provide acceptable sensitivity for a wide range of applications.

5. Equipment and Procedure

5.1 *System Configuration* — Many different radioscopic examination system configurations are possible, and it is important to understand the advantages and limitations of each. It is important that the optimum radioscopic examination system be selected for each examination requirement through a careful analysis of the benefits and limitations of the available system components and the chosen system configuration. The provider as well as the user of the radioscopic examination services should be fully aware of the capabilities and limitations of the radioscopic examination system that is proposed for examination of the test object. The provider and the user of radioscopic examination services shall agree upon the system configuration to be used for each radioscopic examination application under consideration, and how its performance is to be evaluated.

5.1.1 The minimum radioscopic examination system configuration will include an appropriate source of penetrating radiation, a means for positioning the test object within the radiation beam, in the case of dynamic radioscopy, and a detection system. The system may be as simple as a directly viewed fluorescent screen with suitable radiation shielding for personnel protection that meets applicable radiation safety codes.

5.1.2 A more complex system might include the following components:

5.1.2.1 A microfocus X-ray system to facilitate high-resolution projection imaging;

5.1.2.2 A multiple axis test part manipulation system to provide dynamic, full volumetric test part manipulation under operator joystick or automated program control, for dynamic radioscopy;

5.1.2.3 An electronic imaging system to display a bright, two-dimensional gray-scale image of the test part at the operator's control console;

5.1.2.4 A digital image processing system to perform image enhancement and image evaluation functions;

5.1.2.5 An archival quality image recording system; and

5.1.2.6 A radiation protective enclosure with appropriate safety interlocks and a radiation warning system.

5.1.3 Whether a simple or a complex system is used, the system components and configuration utilized to achieve the prescribed test results must be carefully selected.

5.2 *Practice:*

5.2.1 The purchaser and supplier for radioscopic examination services shall mutually agree upon a written procedure using the applicable annex of supplemental requirements and also consider the following general requirements.

5.2.1.1 *Equipment Qualifications* — A listing of the system features that must be qualified to ensure that the system is capable of performing the desired radioscopic examination task.

5.2.1.2 *Test Object Scan Plan* — A listing of test object orientations, ranges of motions, and manipulation speeds through which the test object must be manipulated to ensure satisfactory examination.

5.2.1.3 *Radioscopic Parameters* — A listing of all the radiation source–related variables that can affect the examination outcome for the selected system configuration such as: source energy, intensity, focal spot size,

range of source to object distances, range of object to image plane distances, and source to image plane distances.

5.2.1.4 *Image Processing Parameters* — A listing of all the image processing variables necessary to enhance fine detail detectability in the test object and to achieve the required sensitivity level. These would include, but are not limited to, techniques such as noise reduction, contrast enhancement, and spatial filtering. Great care should be exercised in the selection of directional image processing parameters such as spatial filtering, which may emphasize features in certain orientations and suppress them in others. The listing should indicate the means for qualifying image processing parameters.

5.2.1.5 *Image Display Parameters* — A listing of the techniques and the intervals at which they are to be applied for standardizing the video image display as to brightness, contrast, focus, and linearity.

5.2.1.6 *Accept/Reject Criteria* — A listing of the expected kinds of test object imperfections and the rejection level for each.

5.2.1.7 *Performance Evaluation* — A listing of the qualification tests and the intervals at which they are to be applied to ensure that the radioscopic examination system is suitable for its intended purpose.

5.2.1.8 *Image Archiving Requirements* — A listing of the requirements, if any, for preserving a historical record of the examination results. The listing may include examination images along with written or electronically recorded alpha-numeric or audio narrative information, or both, sufficient to allow subsequent reevaluation or repetition of the radioscopic examination.

5.2.1.9 *Operator Qualifications* — Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or a standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, or a similar document, to the level appropriate for the performance of the listed radioscopic examination.

6. Radioscopic Examination System Performance Considerations and Measurement

6.1 *Factors Affecting System Performance* — Total radioscopic examination system performance is determined by the combined performance of the system components, which include the radiation source, manipulation system (for dynamic radioscopy), detection system, information processing system, image display, automatic evaluation system, and examination record archiving system.

6.1.1 *Radiation Sources* — While the radioscopic examination systems may utilize either radioisotope or X-ray sources, X-radiation, is used for most radioscopic examination applications. This is due to the energy spectrum of the X-radiation, which contains a blend of contrast-enhancing longer wavelengths, as well as the more penetrating, shorter wavelengths. X-radiation is adjustable in energy and intensity to meet the radioscopic examination test requirements, and has the added safety feature of discontinued radiation production when switched off. A radioisotope source has the advantages of small physical size, portability, simplicity, and uniformity of output.

6.1.1.1 X-ray machines produce a more intense X-ray beam emanating from a smaller focal spot than do radioisotope sources. X-ray focal spot sizes range from a few millimeters down to a few micrometers. Reducing the source size reduces geometric unsharpness, thereby enhancing detail sensitivity. X-ray sources may offer multiple or variable focal spot sizes. Smaller focal spots produce higher resolution and provide reduced X-ray beam intensity, while larger focal spots provide higher X-ray intensity and produce lower resolution. Microfocus X-ray tubes are available with focal spots that may be adjusted to as small as a few micrometers in diameter, while still producing an X-ray beam of sufficient intensity so as to be useful for the radioscopic examination of finely detailed test objects.

6.1.1.2 Conventional focal spots of 1.0 mm and larger are useful at low geometric magnification values close to 1×. Fractional focal spots ranging from 0.4 mm up to 1.0 mm are useful at geometric magnifications of up to approximately 2×. Minifocus spots in the range from 0.1 mm up to 0.4 mm are useful at geometric magnifications up to about 6×. Greater magnifications suggest the use of a microfocus spot size of less than 0.1 mm in order to minimize the effects of geometric unsharpness. Microfocus X-ray tubes are capable of focal spot sizes of less than 10 micrometers (10^{-8} meters) and are useful for geometric magnifications of more than 100×.

6.1.2 *Manipulation System for Dynamic Radioscopy* — The test part manipulation system has the function of holding the test object and providing the necessary degrees of freedom, ranges of motion, and speeds of travel to position the test object areas of interest in the radiation beam in such a way so as to maximize the radioscopic examination system's response. In some applications it may be desirable to manipulate the radiation source and detection system instead of, or in addition to, the test object. The manipulation system must be capable of smooth well-controlled motion, especially so for high-magnification microfocus techniques, to take full

advantage of the dynamic aspects of the radioscopic examination.

6.1.3 *Detection System* — The detection system is a key element. It has the function of converting the radiation input signal containing test part information, into a corresponding optical or electronic output signal while preserving the maximum amount of test object information. The detector may be of one-dimensional design, providing test part information one line at a time, or may be a two-dimensional area detector providing an area field of view.

6.1.4 *Information Processing of System:*

6.1.4.1 The function of the information processing system is to take the output of the detection system and present a useful image for display and operator interpretation, or for automatic evaluation. The information processing system may take many different forms, and may process analog or digital information, or a combination of the two.

6.1.4.2 The information processing system includes all of the optics, electronics, and interfaces after the detection system to and including the image display and automatic evaluation system. Information system components include such devices as lenses, fiber optic couplings, light amplifiers, video cameras, image processors, and in general any device that processes radioscopic examination information after the detection system.

6.1.4.3 The digital image processing system warrants special attention, since it is the means by which radioscopic examination information may be enhanced. Great care must be exercised in determining which image processing techniques are most beneficial for the particular application. Directional spatial filtering operations, for example, must be given special attention as certain feature orientations are emphasized while others are suppressed. While many digital image processing operations occur sufficiently fast to follow time-dependent radioscopic system variables, others do not. Some image processing operations require significant image acquisition and processing time, so as to limit the dynamic response of the radioscopic exam, in dynamic radioscopic systems.

6.1.5 *Automatic Evaluation System* — Some radioscopic examination applications can be fully automated including the accept/reject decision through computer techniques. The automatic evaluation system's response to various test object conditions must be carefully determined under actual operating conditions. The potential for rejecting good test objects and accepting defective test objects must be considered. Automatic evaluation system performance criteria should be mutually determined by the provider and user of radioscopic examination services.

6.1.6 *Image Display:*

6.1.6.1 The function of the image display is to convey radioscopic information about the test object to the system operator. For manual evaluation systems, the displayed image is used as the basis for accepting or rejecting the test object, subject to the operator's interpretation of the radioscopic image. The image display performance, size, and placement are important radioscopic system considerations.

6.1.6.2 When employing a television image presentation, vertical and horizontal resolution are often not the same. Therefore, the effect of raster orientation upon the radioscopic examination system's ability to detect fine detail, regardless of orientation, must be taken into account.

6.1.7 *Radioscopic Examination Record Archiving System* — Many radioscopic examination applications require an archival quality examination record of the radioscopic examination. The archiving system may take many forms, a few of which are listed in 6.1.7.1 through 6.1.7.11. Each archiving system has its own peculiarities as to image quality, archival storage properties, equipment, and media cost. The examination record archiving system should be chosen on the basis of these and other pertinent parameters, as agreed upon by the provider and user of radioscopic examination services. The reproduction quality of the archival method should be sufficient to demonstrate the same image quality as was used to qualify the radioscopic examination system.

6.1.7.1 Film or paper radiograph of the test object made under the same conditions as the radioscopic examination image;

6.1.7.2 Spot film camera used to photograph the examination image directly from the output of an X-ray image intensifier without the intervening television chain limitations;

6.1.7.3 Photograph of the actual image display;

6.1.7.4 Multiformat camera used to make a photograph of the examination image from the video signal;

6.1.7.5 Video hard copy device used to create a paper facsimile image from the video signal;

6.1.7.6 Laser print hard copy device used to create a film image from the scanned detector output;

6.1.7.7 Video tape recorder used to record the video signal on magnetic tape; characterized by long recording time at video frame rates; useful for capturing test part motion;

6.1.7.8 Digital recording on magnetic disk or tape used to store the image of the test object digitally, characterized by limited storage capacity at video frame rates, therefore limiting the ability to capture test part motion in dynamic radioscopic systems;

6.1.7.9 Digital recording on optical disk used to store the image of the test object digitally; offers larger storage capacity than magnetic disk or tape; consideration should be given to the type of optical storage because there are fundamentally two different types: magneto-optical where radiological data can be erased or altered, and write once read many times (WORM) where a common format is CD-ROM and the radiological data cannot be erased or altered after the disk is created.

6.1.7.10 Electronic digital memory such as ROM (read only memory) or EPROM (erasable programmable read only memory), characterized by relatively limited capacity; and

6.1.7.11 Hologram used to store high-density digital image data on film at high-information density.

6.1.8 *Examination Record Data* — The examination record should contain sufficient information to allow the radioscopic examination test to be reevaluated or duplicated. Examination record data should be recorded contemporaneously with the radioscopic examination image, and may be in writing or a voice narrative, providing the following minimum data:

6.1.8.1 Radioscopic examination system designation, test date, operator identification, operating turn or shift, and other pertinent test and customer data;

6.1.8.2 Specific test part data as to part number, batch, serial number, etc. (as applicable);

6.1.8.3 Test part orientation and examination site information by manipulation system coordinate data or by reference to unique test part features within the field of view; and

6.1.8.4 System performance monitoring by recording the results of the prescribed radioscopic examination system performance monitoring tests, as set forth in Section 5, at the beginning and end of a series of radioscopic examinations, not to exceed the interval set forth in 6.2.1 for system performance monitoring.

6.2 *Performance Measurement* — Radioscopic examination system performance parameters must be determined initially and monitored regularly to ensure consistent results. The best measure of total radioscopic examination system performance can be made with the system in operation, utilizing a test object similar to the test part under actual operating conditions. This indicates the use of an actual or simulated test object or calibration block containing actual or simulated features that must be reliably detected. Such a calibration block will provide a reliable indication of the radioscopic examination system's capabilities. Conventional wire-or plaque-type IQIs may be used in place of, or in addition to, the simulated test object or calibration block. Performance measurement methods are a matter of agreement between the provider and user of radioscopic examination services.

6.2.1 *Performance Measurement Intervals* — System performance measurement techniques should be standardized so that performance measurement tests may be readily duplicated at specified intervals. Radioscopic examination system performance should be evaluated at sufficiently frequent intervals, as may be agreed upon by the supplier and user of radioscopic examination services, to minimize the possibility of time-dependent performance variations.

6.2.2 *Measurement With IQIs* — Radioscopic examination system performance measurement using IQIs shall be in accordance with accepted industry standards describing the use of IQIs. The IQIs should be placed on the test object as close as possible to the region of interest. The use of wire-type IQIs should also take into account the fact that the radioscopic examination system may exhibit asymmetrical sensitivity, in which case the wire diameter axis shall be oriented along the system's axis of least sensitivity. Selection of IQI thickness should be consistent with the test part radiation path length thickness.

6.2.3 *Measurement With a Calibration Block* — The calibration block may be an actual test object with known features that are representative of the range of features to be detected, or may be fabricated to simulate the test object with a suitable range of representative features. Alternatively, the calibration block may be a one-of-a-kind or few-of-a-kind reference test object containing known imperfections that have been verified independently. Calibration blocks containing known, natural defects are useful on a single-task basis, but are not universally applicable. Where standardization among two or more radioscopic examination systems is required, a duplicate manufactured calibration block should be used. The calibration blocks should approximate the test object as closely as is practical, being made of the same material with similar dimensions and features in the radioscopic examination region of interest. Manufactured calibration blocks should include features at least as small as those that must be reliably detected in the actual test objects in locations where they are expected to occur in the actual test object. Where features are internal to the test object, it is permissible to produce the calibration block in sections. Calibration block details are a matter of agreement

between the user and supplier of radioscopic examination services.

6.2.3.1 *Use of a Calibration Block* — The calibration block should be placed into the radioscopic examination system in the same position as the actual test object and may be manipulated through the same range of motions through a given exposure for dynamic radioscopic systems as are available for the actual test object, so as to maximize the radioscopic examination system's response to the simulated imperfection.

6.2.3.2 *Radioscopic Examination Techniques* — (radiation beam energy, intensity, focal spot size, enlargement, digital image processing parameters, manipulation scan plan for dynamic radioscopic systems, scanning speed, and other system variables) utilized for the calibration block shall be identical to those used for the actual examination of the test object.

6.2.4 *Use of Calibrated Line Pair Test Pattern and Step Wedge:*

6.2.4.1 A calibrated line pair test pattern and step wedge may be used, if so desired, to determine and track radioscopic system performance in terms of spatial resolution and contrast sensitivity. The line pair test pattern is used without an additional absorber to evaluate system spatial resolution. The step wedge is used to evaluate system contrast sensitivity.

6.2.4.2 The step wedge must be made of the same material as the test part with steps representing 100%, 99%, 98%, and 97% of both the thickest and the thinnest material sections to be examined. The thinner steps shall be contiguous to their respective 100% section thicknesses in order to facilitate discerning the minimum visible thickness step. Other thickness steps are permissible upon agreement between the provider and the user of radioscopic services.

6.2.4.3 The line pair test pattern and the step wedge tests shall be conducted in a manner similar to the performance measurements for the IQI or the calibration block set forth in 6.2.2 and 6.2.3. It is permissible to adjust the X-ray energy and intensity to obtain a usable line pair test pattern image brightness. In the case of a radioisotope or X-ray generating system where the energy or intensity may not be adjusted, additional filtration may be added at the radiation source to reduce the brightness to a useful level. Contrast sensitivity shall be evaluated at the same energy and intensity levels as are used for the radioscopic technique.

6.2.4.4 A system that exhibits a spatial resolution of 3 line pairs/mm, a thin section contrast sensitivity of 3%, and a thick section contrast sensitivity of 2% may be said to have an equivalent performance level of 3%–2%–3 lp/mm.

6.2.4.5 The line pair test pattern and the step wedge may be used to make more frequent periodic system performance checks than required in accordance with 6.2.1. Resolution and contrast sensitivity checks must be correlated with IQI or calibration block performance measurements. This may be done by first evaluating system measurement in accordance with 6.2.2 or 6.2.3 and immediately thereafter determining the equivalent spatial resolution and contrast sensitivity values.

6.2.5 *Importance of Proper Environmental Conditions* — Environmental conditions conducive to human comfort and concentration will promote examination efficiency and reliability, and must be considered in the performance of manual evaluation radioscopic examination systems. A proper examination environment will take into account temperature, humidity, dust, lighting, access, and noise level factors. Proper reduced lighting intensity is extremely important to provide for high-contrast glare-free viewing of radioscopic examination images.

7. Radioscopic Examination Interpretation and Acceptance Criteria

7.1 *Interpretation* — Interpretation may be done either by an operator in a manual evaluation radioscopic environment, or by means of a computer and appropriate software in the case of an automated radioscopic examination system. A hybrid environment may also be utilized whereby the computer and software present to the operator a recommended interpretation, which is then subject to the operator's final disposition.

7.2 *Operator* — The supplier and user should reach an agreement as to operator qualifications including duty and rest periods. Recommended Practice SNT-TC-1A sets forth three levels of nondestructive testing personnel qualifications that the radioscopic examination practitioner may find useful.

7.3 *Accept/Reject Criteria* — Accept/reject criteria are a matter of contractual agreement between the provider and the user of radioscopic examination services.

8. Records, Reports, and Identification of Accepted Material

8.1 Records and reports are a matter of agreement between the supplier and the user. If an examination

record archiving requirement exists, refer to 6.1.8, which outlines the necessary information that should be a part of an archival examination record.

9. Safety Conditions

9.1 Radioscopic examination procedures shall be carried out under protective conditions so that personnel will not receive radiation dose levels exceeding that permitted by company, city, state, or national regulations. The recommendations of the National Committee on Radiation Protection should be the guide to radiation safety.

10. Keywords

10.1 analog; detector; digital; display; examination; image; manipulator; processor; radioscopy; source

ANNEXES

(Mandatory Information)

A1. DEPARTMENT OF DEFENSE CONTRACTS, SUPPLEMENTAL REQUIREMENTS

A1.1 *Scope*

A1.1.1 *Purpose* — This annex is to be used in conjunction with Practice E 1255 and MIL-STD-453. It permits the use of and gives guidance on the implementation of radioscopic examination for materials, components, and assemblies, when specified in the contract documents. The radioscopic requirements described herein allow the use of radioscopy for new applications as well as to replace radiography when inspection coverage, greater throughput, or improved inspection economics can be obtained, provided a satisfactory level of image quality can be demonstrated.

A1.1.2 *Application* — This annex provides guidelines for a written practice as required in 3.2 and 5.2.1 of Practice E 1255. Should the requirements in this annex conflict with any other requirements of Practice E 1255, then Annex A1 takes precedence. The requirements of this annex are intended to control the quality of the radioscopic examination and not to specify the accept/reject criteria for the test object. Accept/reject criteria are provided in other contract documents.

A1.2 *Referenced Documents*

A1.2.1 In addition to those documents referenced in Practice E 1255, the following standards are applicable to the extent specified herein.

A1.2.2 *ASTM Standards:*

E 1411 Practice for Qualification of Radiographic Systems

E 1453 Guide for Storage of Media That Contains Analog or Digital Radiographic Data

A1.2.3 *Military Standards:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

MIL-STD-453 Inspection, Radiographic

DOD-STD-2167 Defense System Software Development

A1.2.4 *American Welding Society Standard:*

ANSI/AWS 3.0 Welding Terms and Definitions

A1.2.5 *Government Standards* — Unless otherwise stated, the issues of these documents are those listed in the Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the contract document.

A1.2.6 *Order of Preference* — In the event of conflict between the text of this document and the references listed in A1.2.2, this document shall take precedence. However, nothing in this document shall supersede applicable laws and regulations unless a specific exemption has been obtained from the cognizant authorities.

A1.3 Terminology

A1.3.1 *component* — the test part or parts described, assembled, or processed to the extent specified by the drawing.

A1.3.2 *contracting agency* — a prime contractor, subcontractor, or government agency that procures radioscopic examination services.

A1.3.3 *contract documents* — the procuring contract and all drawings, specifications, standards, and other information included with or referred to by the procuring contract.

A1.3.4 *mandatory radioscopic examination* — those radioscopic examinations which are a part of the required radiographic examinations specified in the contract documents.

A1.3.5 *NDT facility* — the organization that is responsible for the providing of nondestructive examination services.

A1.3.6 *optional radioscopic examination* — those radioscopic examinations which are conducted for process verification or information only and are not a part of the required radiographic examination specified in the contract documents.

A1.3.7 *prime contractor* — a contractor having responsibility for the design control and delivery to the department of defense for system/equipment such as aircraft, engines, ships, tanks, vehicles, guns and missiles, ground communications and electronic systems, ground support, and test equipment.

A1.3.8 *test object* — the material, component or assembly that is the subject of the radioscopic examination.

A1.3.9 *written procedure* — in radioscopy, a series of steps that are to be followed in a regular definite order. The radioscopic system operator follows the written procedure to consistently obtain the desired results and image quality level when performing radioscopic examination. The development of a radioscopic technique usually precedes the preparation of a written procedure.

A1.3.10 Other definitions not given herein shall be as specified in Terminology E 1316.

A1.4 General Requirements

A1.4.1 *Equipment Qualification* — Radioscopic system qualification shall be in accordance with Practice E 1411 and can best be evaluated with IQIs similar to the flaw type being investigated. A common IQI is described in MIL-STD-453.

A1.4.2 *Personnel Qualification* — Radioscopic personnel shall be qualified and certified in accordance with the general requirements of MIL-STD-410, until specific requirements for radioscopy are included. Radioscopic system qualification, the development of radioscopic examination test techniques, scan plans, and the overall implementation of radioscopic examination in accordance with this annex, shall be under the control and supervision of a qualified MIL-STD-410 Level III with additional radioscopy training and experience or in conjunction with an individual having the necessary training and experience in radioscopic examination.

A1.4.3 *Safety* — The performance or radioscopic examination shall present no hazards to the safety of personnel or property. Applicable Federal, state, and local radiation safety codes shall be adhered to. All radioscopic procedures shall be performed in a safe manner, such that personnel in that area are not exposed to any radiation dosage and shall in no case exceed Federal, state, and local limits.

A1.4.4 *Archival Recording of Mandatory Radioscopic Examination* — When required by contractual agreement, the radioscopic examination record shall contain the results of mandatory radioscopic examinations. The radioscopic examination record shall be suitably archived for a period of time not less than five years from the examination date or as may otherwise be required in the contract documents. Efficient radioscopic examination record recall shall be available at any time over the record retention period. The radioscopic examination record shall be traceable to the test object (by serial number or other means) or to the batch or lot number, if tested in groups. Mandatory radioscopic examinations shall be specified in the contract documents. The optional radioscopic examinations are not specified in the contract documents.

A1.4.4.1 *Radioscopic Examination Record* — The recorded radioscopic examination record for mandatory examinations shall include the written results of the radioscopic examination and the radioscopic image, if an image is utilized in the accept/reject decision-making process. The recorded radioscopic image shall be provided with such additional information as may be required to allow the subsequent off-line review of the radioscopic examination results and, if necessary, the repeating of the radioscopic examination.

A1.4.4.2 *Image Recording Media* — The radioscopic image shall be recorded on a media that is appropriate to the radioscopic examination requirement. The recorded image shall reference the examination zones in such a way that the reviewer can confirm that all zones have been covered. The recorded radioscopic image shall provide an image quality at least equal to that for which the radioscopic system is qualified. The recording media shall be capable of maintaining the required image quality for the required record storage period or not less than five years from the recording date. The radioscopic image record shall be maintained in an operable condition for the duration of the record storage period, measured from the date when the last radioscopic image was recorded.

A1.4.4.3 *Recording Media Storage Conditions* — Media storage and handling shall be in accordance with Guide E 1453.

A1.4.5 *Image Quality Indicators* — Image quality indicators must be chosen with care to demonstrate the radioscopic system's ability to detect discontinuities or other features that are of interest. MIL-STD-453, Practice E 1025 plaque-type, and Practice E 747 wire-type IQIs and calibration blocks with real or simulated defects, to match the application, are all acceptable unless a particular IQI is specified in the contract documents. The selected IQI or calibration block shall be detailed in the written procedure. An IQI or calibration block may not be required for the following radioscopic examinations:

A1.4.5.1 When conducting radioscopy to check for adequate defect removal or grind-out, the final acceptance radioscopic examination shall include an IQI;

A1.4.5.2 Examinations to show material details or contrast between two or more dissimilar materials, in component parts or assemblies, including honeycomb areas for the detection of fabrication irregularities or the presence or absence of material;

A1.4.5.3 Examinations of electronic components for contamination, loose or missing elements, solder balls, broken or misplaced wires or connectors, and potted assemblies for broken internal components or missing potting compound;

A1.4.5.4 Optional radioscopic examinations; and

A1.4.5.5 Where the use of an IQI is impractical or ineffective, an alternate method may be used, subject to the approval of the contracting agency.

A1.4.6 *Classification of Test Object Zones for Radioscopy* — The classification of test objects into zones for various accept/reject criteria shall be determined from the contract documents.

A1.5 Detailed Requirements

A1.5.1 *Application Qualification:*

A1.5.1.1 *New Applications* — Radioscopy may be used where appropriate for new examination requirements, provided the required performance, including image quality, can be met.

A1.5.1.2 *Replacement of Existing Radiographic Applications* — When agreed to by the contracting officer, radioscopy may be used to replace or augment existing radiographic applications, provided that the radioscopic results correlate favorably with the results obtained with X-ray film produced in accordance with MIL-STD-453. Favorable correlation means that the radioscopic and film images show similar sensitivity to test object features that are of interest.

A1.5.2 *Written Procedure* — It shall be the responsibility of the NDE facility to develop a written radioscopic examination procedure to ensure the effective and repeatable radioscopic examination of the test object. A test object scan plan for dynamic radioscopic systems, meeting the requirements of Practice E 1255 (see 5.2.1.2), shall be included in the written procedure. Those portions of the contract document that specify and detail radioscopic examination shall become an appendix to the written procedure. The written procedure must be approved by the Level III of the NDE facility. Where required, the written procedure shall be approved by the contracting agency prior to use. The written procedure shall include as a minimum the following information:

A1.5.2.1 A drawing, sketch, or photograph of the component that shows the radiation beam axis, positions(s) of the detector, and applicable IQI for each and all variations of the test object orientation and beam energy. This requirement may be expressed in coordinates for automated systems having calibrated manipulation systems;

A1.5.2.2 A physical description of the test object, including size, thickness, weight, and composition;

A1.5.2.3 Classification of the test object into zones for radioscopy;

A1.5.2.4 Test part masking, if used, for each required view;

A1.5.2.5 Added radiation source collimation, expressed in terms of the radiation field dimensions at the test object source side, for each required view;

A1.5.2.6 Detector field of view for each required view;

A1.5.2.7 Detector diaphragm settings, expressed in terms of field of view at the detector, for each required view;

A1.5.2.8 The allowable range of radiation energy and beam current or source intensity and the focal spot or source size for each required view;

A1.5.2.9 Added beam filtration, if used, for each required view;

A1.5.2.10 The inspection geometry and coverage for each required view;

A1.5.2.11 Type of IQI or calibration block used and the required quality level;

A1.5.2.12 All hardware and software settings that can be changed by the operator to affect the outcome of the radioscopic examination. Such settings include, but are not limited to, video camera and display settings and image processor variables; and

A.1.5.2.13 The recording media and storage image format for mandatory radioscopic image storage.

A1.5.3 *Test Object Examination* — The number of test objects to be examined and the coverage required for each test object shall be specified in the contract documents. If not specified, all test objects shall receive 100% radioscopic coverage as detailed in the written procedure.

A1.5.4 *Image Quality* — Unless otherwise specified in the contract documents, the required image quality level is 2-2*T*. Image quality assessment shall be performed using the same system parameters as in the inspection and as documented in the written procedure.

A1.5.4.1 The IQI may be placed on the test object or on a mounting block, at or near the test object location, following the requirements of MIL-STD-453. In the case of small radioscopic fields of view or other situations where it is not practical to place the IQI in the field of view with the test object and maintain it normal to the X-ray beam, the IQI may be imaged immediately before and after the test object examination. Batch quantities of similar parts need not have IQI images made between each part, at the discretion of the Level III. The radioscopic examination results shall be invalid, if the before and after IQI images fail to demonstrate the required

sensitivity. The before and after IQI images shall be considered a part of the test object image for radioscopic image interpretation and archiving purposes.

A1.5.4.2 With written permission from the contracting agency, other IQIs or a calibration block with natural or artificial flaws may be used instead of the specified IQI.

A1.5.5 *Radioscopic System Qualification* — The radioscopic system, including mandatory radioscopic image archiving devices, shall be qualified to the image quality level required for test object examination. Radioscopic system initial qualification shall be in accordance with Practice E 1411.

A1.5.6 *Radioscopic System Requalification* — The radioscopic system, including mandatory image archiving devices, shall be periodically requalified at intervals frequent enough to ensure the required level of radioscopic system performance. Each requalification shall be carried out in accordance with Practice E 1411.

A1.5.7 *Inspection Image Control* — The radioscopic system shall be checked for performance before each day's production usage using the method and devices that were initially used to qualify the written procedure. A log shall be maintained to document any changes in system performance requiring changes in operating parameters and listing all equipment maintenance. System requalification shall be required whenever image quality requirements can no longer be met.

A1.5.8 *Repair of Radioscopic System* — Repair or replacement of key radioscopic system components including, but not limited to, the radiation source, image forming, image transmission, image processing, and image display subsystems shall be cause for system requalification. In no case shall the interval between qualification tests exceed one year. The qualification statement shall be posted on the radioscopic system. The results of the qualification tests shall be maintained in the radioscopic system equipment file until the completion of the next qualification procedure or the expiration of the archival image retention period, whichever is longer.

A1.5.9 *Image Interpretation:*

A1.5.9.1 *Static Imaging* — Radioscopic system qualification in accordance with Practice E 1411 applies to static imaging conditions only where the test part is stationary with respect to the X-ray beam. Therefore, all performance measurements are based upon static image quality. All mandatory radioscopic examination accept/reject decisions shall be based upon the assessment of static images.

A1.5.9.2 *Dynamic Imaging* — Dynamic or in-motion imaging may be used to gain useful information about the test object. However, unless dynamic imaging is specified, the final assessment of image formation for mandatory radioscopic examinations shall be made in the static mode. When the contracting agency specifies dynamic inspection, all aspects of the procedure must be approved by MIL-STD-410 Level III personnel. For dynamic inspection, the image quality shall be measured under the same procedure as the inspection.

A1.5.10 *Feature Size Determination* — Where feature measurement from the radioscopic image is required, the written procedure shall include methodology for determining and maintaining the accuracy of the selected measurement method.

A1.5.10.1 *Feature Measurement by Test Object Displacement* — For those radioscopic systems with calibrated manipulation systems, the more accurate, and therefore preferred, method of measurement is to manipulate the extremities of the feature to be measured to a common central reference point within the radioscopic image field of view. The dimension may then be read from the manipulation system position display.

A1.5.10.2 *Feature Measurement by Comparison* — A second method involves comparing the test object feature with a known, observable dimension which must be wholly within the radioscopic field of view. Many digital image processors facilitate this type of measurement by counting pixels over the feature length. The pixel number is often converted to engineering units by comparison with a known length. However, the orientation and position along the X-ray beam (magnification) of both the feature and the calibrating reference length affect the accuracy of such measurements.

A1.5.11 *Gray Scale Range* — The gray scale range required to meet initial qualification contrast sensitivity requirements for image quality shall be recorded and monitored. For systems using human image assessment, it is particularly important that the gray scale range and the number of gray scale steps be closely matched to the response of the human eye. The written procedure shall include a means for monitoring the required gray scale range using a contrast sensitivity gage, step wedge, or similar device made of the test object or IQI material.

A1.5.12 *Timing of Radioscopic Examination* — Radioscopic examination shall be performed at the time of manufacturing, assembly, or rework as required by the contract documents.

A1.5.13 *Identification* — A means shall be provided for the positive identification of the test object to the archival radioscopic inspection record. Archived radioscopic images shall be annotated to agree with the test object identification.

A1.5.14 *Locating the Radioscopic Examination Areas* — Whenever more than one image is required for a weldment or other test object, location markers shall be placed on the test object in order that the orientation of the test object and the location of test object features relative to the radioscopic field of view may be established. This requirement shall not apply to automated systems having programmed radioscopic examination sequences where coverage has been proven during the development of the scan plan. Also, this requirement does not apply to the radioscopic examination of simple or small shapes where the test part orientation is obvious and coverage is not in question.

A1.5.15 *Surface Preparation* — Test objects may be inspected without surface preparation, except when required to remove surface conditions that may interfere with proper interpretation of the radioscopic image or that may create a safety hazard.

A1.5.16 *Detailed Data* — The provider of radioscopic examination services shall keep the written procedure, qualification documentation, and the signed inspection reports or tabulated results, or both, for five years from the radioscopic examination date, unless otherwise specified in the contract documents. For software-based automated radioscopic systems using custom software, a copy of the source code and the related inspection parameters shall also be maintained on file for a like period of time. This requirement shall not apply to standard commercially available software packages or to traceable software documentation which complies with DOD-STD-2167 where a separate copy of the software is maintained.

A1.5.17 *Radioscopic Reexamination of Repairs* — When repair has been performed as the result of radioscopic examination, the repaired areas shall be reexamined using the same radioscopic technique to evaluate the effectiveness of the repair. Each repaired area shall be identified with R1, R2, R3, and so forth, to indicate the number of times repair was performed.

A1.5.18 *Retention of Radioscopic Examination Records* — Mandatory radioscopic examination records and associated radioscopic images shall be stored in a proper repository at the contractor's plant for five years from the date from which they were made. Special instructions, such as storage for other periods of time, making backup copies, copying the records to other media, or having the records destroyed shall be specified in the contract documents.

A1.5.19 *Rejection of Test Objects* — Test objects containing defects exceeding the permissible limits specified in the contract documents shall be separated from acceptable material, appropriately identified as discrepant, and submitted for material review when required by the contract documents.

A1.5.20 *Reexamination* — When there is a reasonable doubt as to the ability to interpret the radioscopic results because of improper execution or equipment malfunction, the test object shall be reexamined using the correct procedure. If the problem is not resolved by reexamination, the procedure shall be reviewed by the Level III of the NDE facility and adjusted, if necessary. Reference exposures may be made using radiography if necessary. If the reexamination was caused by equipment malfunction, the equipment may not be returned to service until the malfunction is repaired and the equipment is requalified to the current qualification requirements in accordance with Practice E 1411.

A1.5.21 *Test Object Marking* — The marking of test objects shall be as specified in MIL-STD-453.

A1.6 Notes

A1.6.1 This section contains information of a general or explanatory nature and is not mandatory.

A1.6.1.1 Caution — Active electronic components and some materials, such as tetrafluoroethylene, are subject to radiation damage if exposed to large doses of radiation. While normal radioscopic examinations should cause no problem, extended periods of radiation exposure should be avoided.

A1.6.1.2 *Human Factors* — The success of radioscopic examinations which involve human image interpretation are, like radiography, subject to human factors. Careful attention should be given to the human environment where image interpretation takes place, to make it as conducive to correct, consistent image interpretation as possible. Measures should also be implemented to ensure that fatigue does not interfere with correct and consistent radioscopic image interpretation.

A1.6.1.3 *Use of IQI(s)* — As with radiography, the achievement of the required IQI sensitivity does not guarantee the ability to find all defects down to the minimum defect size. This is due to the fact that many defects, especially those of a planar nature, are very orientation sensitive. When using dynamic radioscopic systems, care must be taken to see that the scan plan includes sufficient manipulations to maximize the possibility that orientation-sensitive defects will be found. It is for this reason that the use of calibration blocks with real or simulated defects may more accurately characterize the ability of the radioscopic system to find orientation-sensitive defects when using dynamic radioscopic systems.

A1.6.1.4 *Use of Image-Processing Techniques* — Care should be exercised in applying digital image–processing techniques to evaluate the overall effect upon image quality. For example, contrast enhancement techniques may emphasize contrast in one brightness range, while decreasing contrast in other brightness ranges. Some spatial filters have directional aspects, whereby features in one direction are emphasized while those in the orthogonal direction are deemphasized. Such cautions are intended to cause the careful evaluation of digital image–processing techniques and not to discourage their use.

A1.6.1.5 *Feature Size Determination* — As with radiography, great care must be exercised in trying to assess test part feature dimensions from a two-dimensional projected view.

A2. NONGOVERNMENT CONTRACT SUPPLEMENTAL REQUIREMENTS

A2.1 Scope

A2.1.1 *Purpose* — This annex is to be used in conjunction with Practice E 1255. This annex includes application-specific details as may be agreed upon by the purchaser and the supplier of radioscopic examination services.

A2.1.2 *Application* — This document satisfies the requirements of 3.2 and 5.2.1 of Practice E 1255. Should this annex conflict with any other requirements of Practice E 1255, this annex shall prevail. The requirements of this annex are intended to control the quality of the radioscopic examination and not to specify the accept/reject criteria for the test object. Accept/reject criteria are provided in other contract documents.

A2.2 Terminology

A2.2.1 *component* — the test part or parts described, assembled, or processed to the extent specified by the drawing.

A2.2.2 *contract documents* — the procuring contract and all drawings, specifications, standards, and other information included with or referred to by the procuring contract.

A2.2.3 *contractor* — a contractor having first level responsibility for the design, manufacture, and delivery of an end item. When radioscopic examination is required, the contractor is the user of radioscopic examination services.

A2.2.4 *mandatory radioscopic examination* — those radioscopic examinations which are a part of the required radiographic examinations specified in the contract documents.

A2.2.5 *NDE facility* — the organization that is responsible for providing nondestructive examination services.

A2.2.6 *optional radioscopic examination* — those radioscopic examinations that are conducted for process verification or information only and are not a part of the required radiographic examinations specified in the contract documents.

A2.2.7 *provider of radioscopic services* — a contractor, subcontractor, or other entity that provides radioscopic examination services.

A2.2.8 *test object* — the material, component, or assembly that is the subject of the radioscopic examination.

A2.2.9 *user of radioscopic services* — a contractor, subcontractor, or other entity that procures radioscopic examination services. The provider and user of radioscopic examination services may be a part of the same organization or different organizations.

A2.2.10 *written procedure* — in radioscopy, a series of steps that are to be followed in a regular definite order. The radioscopic system operator follows the written procedure to consistently obtain the desired results and image quality level when performing radioscopic examination. The development of a radioscopic technique usually precedes the preparation of a written procedure.

A2.2.11 Other definitions not given herein shall be as specified in Terminology E 1316.

A2.3 General Requirements

A2.3.1 *Equipment Qualification* — Radioscopic system qualification shall be in accordance with Practice E 1411, using Practice E 747 and Practice E 1025 image quality indicators or a calibration block containing actual or simulated defects.

A2.3.2 *Personnel Qualification* — Radioscopic personnel shall be qualified and certified in accordance with the requirements of SNT-TC-1A or ANSI/ASNT CP-189. Radioscopic system qualification, the development of radioscopic examination test techniques, scan plans, and the overall implementation of radioscopic examination in accordance with this annex shall be under the control and supervision of a qualified Level III with additional radioscopy training and experience, or in conjunction with an individual having the necessary training and experience in radioscopic examination. Operation of the radioscopic system, including interpretation of the radioscopic image, shall be made by qualified Level II personnel.

A2.3.3 *Safety* — The performance of radioscopic examination shall present no hazards to the safety of personnel or property. Applicable Federal, state, and local radiation safety codes shall be adhered to. All radioscopic procedures shall be performed so that personnel shall receive the minimum dosage and in no case exceed Federal, state, and local limits.

A2.3.4 *Archival Recording of Mandatory Radioscopic Examinations* — The radioscopic examination record shall contain the results for mandatory radioscopic examinations. The radioscopic examination record shall be suitably archived for a period of one year after the date of radioscopic examination or for a longer time if specified in the contract documents. Efficient radioscopic examination record recall shall be available at any time over the record retention period. The radioscopic examination record shall be traceable to the test object by serial number or other means. This requirement will not apply to optional radioscopic examinations that are not specified in the contract documents.

A2.3.4.1 *Radioscopic Examination Record* — The recorded radioscopic examination record for mandatory examinations shall include the written results of the radioscopic examination and the radioscopic image, if an image is utilized in the accept/reject decision-making process. The recorded radioscopic image shall be provided with such additional information as may be required to allow the subsequent off-line review of the radioscopic examination results and, if necessary, the repeating of the radioscopic examination.

A2.3.4.2 *Image Recording Media* — The radioscopic image shall be recorded on a media that is appropriate to the radioscopic examination requirement. The recorded image shall reference the examination zones in such a way that the reviewer can confirm that all zones have been covered. The recorded radioscopic image shall provide an image quality at least equal to that for which the radioscopic system is qualified. The recording media shall be capable of maintaining the required image quality for the required record storage period or not less than five years from the recording date. The recorded radioscopic image playback shall be maintained in an operable condition for the duration of the record storage period measured from the date when the last radioscopic image was recorded.

A2.3.4.3 *Recording Media Storage Conditions* — Media storage and handling shall be in accordance with Guide E 1453.

A2.3.4.4 *Other Recording* — Where the recording of the radioscopic examination record is not in fulfillment of mandatory archival recording requirements, other recording methods and media may be used.

A2.3.5 *Image Quality Indicators* — An IQI must be chosen with care to demonstrate the radioscopic system's ability to detect discontinuities, or other features of interest. Practice E 1025 plaque-type and Practice E 747 wire-type IQIs and calibration blocks with real or simulated defects that match the application are all acceptable unless a specific IQI is specified in the contract documents. The selected IQI or calibration block shall be detailed in the written procedure. An IQI or calibration block may not be required for the following radioscopic examinations:

A2.3.5.1 Examining assemblies for debris or foreign objects.

A2.3.5.2 Conducting radioscopy for adequate defect removal or grind-out. However, the final acceptance radioscopic examination shall include an IQI.

A2.3.5.3 Examinations to show material details or contrast between two or more dissimilar materials in component parts or assemblies including honeycomb areas for the detection of fabrication irregularities or the presence or absence of material.

A2.3.5.4 Examining electronic components for contamination, loose or missing elements, solder balls, broken or misplaced wires, or connectors and potted assemblies for broken internal components or missing potting compound.

A2.3.5.5 Optional radioscopic examinations.

A2.3.5.6 Where the use of an IQI is impractical or ineffective, an alternate method may be used, subject to the approval of the contracting agency.

A2.3.6 *Classification of Test Object Zones for Radioscopy* — The classification of test objects into zones for various accept/reject criteria shall be determined from the contract documents. In cases where no accept/reject criteria are specified, the Level III of the NDE facility shall document those anomalies considered critical and indicate in writing that no formal accept/reject criteria were provided.

A2.4 Detailed Requirements

A2.4.1 *Application Qualification* — Radioscopy may be used where appropriate for new as well as existing radiographic examination requirements provided that the required performance, including image quality, can be met. Where radioscopy is used to replace or augment existing radiographic applications, the radioscopic results should correlate favorably with the results obtained with radiographic film-produced techniques. Favorable correlation means that the radioscopic and film images show similar sensitivity to test object features which are of interest.

A2.4.2 *Written Procedure* — It shall be the responsibility of the NDE facility to develop a written radioscopic examination procedure to ensure the effective and repeatable radioscopic examination of the test object. When a dynamic radioscopic system is used, a test object scan plan meeting the requirements of Practice E 1255 (see 5.2.1.2) shall be included in the written procedure. Those portions of the contract document that specify and detail radioscopic examination shall become an appendix to the written procedure. The written procedure must be written or approved by the Level III of the NDE facility. Where required, the written procedure shall be approved by the contracting agency prior to use. The written procedure shall include as a minimum the following information:

A2.4.2.1 A drawing, sketch, or photograph of the component that shows the radiation beam axis, position(s) of the detector and applicable IQI for each and all variations of the test object orientation, and beam energy. This requirement may be expressed in coordinates for automated systems having calibrated manipulation systems.

A2.4.2.2 A physical description of the test object including size, weight, and composition.

A2.4.2.3 Classification of test object into zones for radioscopy.

A2.4.2.4 Test part masking, if used, for each required view.

A2.4.2.5 Added radiation source collimation, expressed in terms of the radiation field dimensions at the test object source side for each required view.

A2.4.2.6 Detector field of view for each required view.

A2.4.2.7 Detector diaphragm settings, expressed in terms of field of view at the detector for each required view.

A2.4.2.8 The allowable range of radiation energy and beam current or source intensity and the focal spot or source size for each required view.

A2.4.2.9 Added beam filtration, if used, for each required view.

A2.4.2.10 The inspection geometry and coverage for each required view.

A2.4.2.11 Type of IQI or calibration block used and the required quality level.

A2.4.2.12 All hardware and software settings which can be changed by the operator to affect the outcome of the radioscopic examination. Such settings include, but are not limited to, video camera, display settings, and image processor variables.

A2.4.2.13 The recording media and stored image format for mandatory radioscopic image storage.

A2.4.3 *Test Object Examination* — The number of test objects to be examined and the coverage required for each test object shall be specified in the contract documents. If not specified, all test objects shall receive 100% radioscopic coverage as detailed in the written procedure.

A2.4.4 *Image Quality* — Unless otherwise specified in the contract documents, the required image quality level is 2-2*T*. Image quality assessment shall be made in the same mode as that used for the inspection.

A2.4.4.1 The IQI may be placed on the test object or on a mounting block at or near the test object location. In the case of small radioscopic fields of view or other situations where it is not practical to place the IQI in the field of view with the test object and maintain it normal to the X-ray beam, the IQI may be imaged immediately before and after the test object examination or batch of test objects if they are similar. The radioscopic examination results shall be invalid if the before and after IQI images fail to demonstrate the required sensitivity. Before and after IQI images shall be considered a part of the test object image for radioscopic image interpretation and archiving purposes.

A2.4.5 *Radioscopic System Qualification* — The radioscopic system including mandatory radioscopic image archiving devices shall be qualified to the image quality level required for test object examination. Radioscopic system initial qualification and periodic requalification shall be in accordance with Practice E 1411.

A2.4.6 *Radioscopic System Requalification* — The radioscopic system, including mandatory image archiving devices, shall be periodically requalified at intervals frequent enough to ensure the required level of radioscopic system performance.

A2.4.7 *Inspection Image Control* — The radioscopic system shall be checked for performance before each day's production usage using the method and devices that were initially used to qualify the written procedure. A log shall be maintained to document any changes in system performance requiring changes in operating parameters and listing all equipment maintenance. System requalification shall be required whenever image quality requirements can no longer be met.

A2.4.8 *Repair of Radioscopic System* — Repair or replacement of key radioscopic system components including but not limited to the radiation source, image

forming, image transmission, image processing, and image display subsystems shall be cause for system requalification. In no case shall the interval between qualification tests exceed one year. The qualification statement shall be posted on the radioscopic system. The results of the qualification tests shall be maintained in the radioscopic system equipment file at least until completion of the next qualification procedure or the expiration of the archival image retention period, whichever is longer.

A2.4.9 *Image Interpretation:*

A2.4.9.1 *Static Imaging* — Radioscopic system qualification in accordance with Practice E 1411 applies to static imaging conditions, only where the test part is stationary with respect to the X-ray beam. Therefore, all performance measurements are based upon static image quality. All mandatory radioscopic examination accept/reject decisions shall be based upon the assessment of static images.

A2.4.9.2 *Dynamic Imaging* — Dynamic or in-motion imaging may be used to gain useful information about the test object. However, the final assessment of image information for mandatory radioscopic examinations shall be made in the static mode.

A2.4.10 *Feature Size Determination* — Where feature measurement from the radioscopic image is required, the written procedure shall include methodology for determining and maintaining the accuracy of the selected measurement method.

A2.4.10.1 *Feature Measurement by Test Object Displacement* — For those radioscopic systems with calibrated manipulation systems, the more accurate and therefore preferred method of measurement is to manipulate the extremities of the feature to be measured to a common central reference point within the radioscopic image field of view. The dimension may then be read from the manipulation system position display.

A2.4.10.2 *Feature Measurement by Comparison* — A second method involves comparing the test object feature with a known, observable dimension which must be wholly within the radioscopic field of view. Many digital image processors facilitate this type of measurement by counting pixels over the feature length. The pixel number is often converted to engineering units by comparison with a known length. However, the orientation and position along the X-ray beam (magnification) of both the feature and the calibrating reference length affect the accuracy of such measurements.

A2.4.11 *Gray Scale Range* — The gray scale range required to meet initial qualification contrast sensitivity requirements for image quality shall be recorded and monitored. For systems using human image assessment, it is particularly important that the gray scale range and the number of gray scale steps be closely matched to the response of the human eye. The written procedure shall include a means for monitoring the required gray scale range using a contrast sensitivity gage, step wedge, or similar device made of the test object or IQI material.

A2.4.12 *Timing of Radioscopic Examination* — Radioscopic examination shall be performed at the time of manufacturing, assembly, or rework as required by the contract documents.

A2.4.13 *Identification* — A means shall be provided for the positive identification of the test object to the archival radioscopic inspection record. Archived radioscopic images shall be annotated to agree with the test object identification.

A2.4.14 *Locating the Radioscopic Examination Areas* — Whenever more than one image is required for a weldment or other test object, location markers shall be placed on the test object in order that the orientation of the test object and the location of test object features relative to the radioscopic field of view may be established. This requirement shall not apply to automated systems having programmed radioscopic examination sequences where coverage has been proven during the development of the scan plan. Also, this requirement does not apply to the radioscopic examination of simple or small shapes where the test part orientation is obvious and coverage is not in question.

A2.4.15 *Surface Preparation* — Test objects may be inspected without surface preparation except as may be required to remove surface conditions which may interfere with proper interpretation of the radioscopic image or create a safety hazard.

A2.4.16 *Detailed Data* — The provider of radioscopic examination services shall keep the written procedure, qualification documentation, and the signed inspection reports or tabulated results for five years from the radioscopic examination date unless otherwise specified in the contract documents. For software-based automated radioscopic systems using custom software, a copy of the source code and the related inspection parameters shall also be maintained on file for a like period of time. This requirement shall not apply to standard commercially available software packages where a separate copy of the software is maintained.

A2.4.17 *Radioscopic Reexamination of Repairs* — When repair has been performed as the result of radioscopic examination, the repaired areas shall be reexamined using the same radioscopic technique to evaluate the effectiveness of the repair. Each repaired area shall

be identified with R1, R2, R3, and so forth, to indicate the number of times repair was performed.

A2.4.18 *Retention of Radioscopic Examination Record* — Mandatory radioscopic examination records and associated radioscopic images shall be stored in a proper repository at the contractor's plant for one year from the date from which they were made. Special instructions, such as storage for other periods of time, making backup copies, copying the records to other media, or having the records destroyed shall be specified in the contract documents.

A2.4.19 *Rejection of Test Objects* — Test objects containing defects exceeding the permissible limits specified in the contract documents shall be separated from acceptable material, appropriately identified as discrepant, and submitted for material review when required by the contract documents.

A2.4.20 *Reexamination* — Where there is an inability to interpret the radioscopic results because of improper execution or equipment malfunction, the test object shall be reexamined using the correct procedure. If the problem is not resolved by reexamination, the procedure shall be reviewed by the Level III of the NDE facility and adjusted, if necessary. Reference exposures may be made using radiography if necessary. If the reexamination was caused by equipment malfunction, the equipment may not be returned to service until the malfunction is repaired and the equipment is requalified to the current qualification requirements in accordance with Practice E 1411.

A2.4.21 *Test Object Disposition* — Test objects that have undergone radioscopic examination shall be marked or physically separated in such a manner so as to minimize the possibility of rejected or questionable test objects being confused with acceptable ones.

A2.5 Notes

A2.5.1 This section contains information of a general or explanatory nature and is not mandatory.

A2.5.1.1 Caution — Active electronic components and some materials, such as tetrafluoroethylene, are subject to radiation damage if exposed to large doses of radiation. While normal radioscopic examinations should cause no problem, extended periods of radiation exposure should be avoided.

A2.5.1.2 *Human Factors* — The success of radioscopic examinations which involve human image interpretation are, like radiography, subject to human factors. Careful attention should be given to the human environment where image interpretation takes place, to make it as conducive to correct, consistent image interpretation as possible. Measures should also be implemented to ensure that fatigue does not interfere with correct and consistent radioscopic image interpretation.

A2.5.1.3 *Use of IQI* — As with radiography, the achievement of the required IQI sensitivity does not guarantee the ability to find all defects down to the minimum defect size. This is due to the fact that many defects, especially those of a planar nature, are very orientation sensitive. When a dynamic radioscopic system is used, care must be taken to see that the scan plan includes sufficient manipulation to maximize the possibility that orientation-sensitive defects will be found. It is for this reason that the use of calibration blocks with real or simulated defects may more accurately characterize the ability of the radioscopic system to find orientation-sensitive defects.

A2.5.1.4 *Use of Image-Processing Techniques* — Care should be exercised in applying digital image–processing techniques to evaluate the overall effect upon image quality. For example, contrast enhancement techniques may emphasize contrast in one brightness range while decreasing contrast in other brightness ranges. Some spatial filters have directional aspects whereby features in one direction are emphasized while those in the orthogonal direction are deemphasized. Such cautions are intended to cause the careful evaluation of digital image–processing techniques and not to discourage their use.

A2.5.1.5 *Feature Size Determination* — As with radiography, great care must be exercised in trying to assess test part feature dimensions from a two-dimensional projected view.

A06

STANDARD TEST METHOD FOR RADIOSCOPIC EXAMINATION OF WELDMENTS

SE-1416

(Identical with ASTM Specification E 1416-04.)

1. Scope

1.1 This test method covers a uniform procedure for radioscopic examination of weldments. Requirements expressed in this test method are intended to control the quality of the radioscopic images and are not intended for controlling acceptability or quality of welds.

1.2 This test method applies only to the use of equipment for radioscopic examination in which the image is finally presented on a television monitor for operator evaluation. The examination may be recorded for later review. It does not apply to fully automated systems where evaluation is automatically performed by computer.

1.3 The radioscopic extent, the quality level, and the acceptance criteria to be applied shall be specified in the contract, purchase order, product specification, or drawings.

1.4 This test method can be used for the detection of discontinuities. This test method also facilitates the examination of a weld from several directions, such as perpendicular to the weld surface and along both weld bevel angles. The radioscopic techniques described in this test method provide adequate assurance for defect detectability; however, it is recognized that, for special applications, specific techniques using more stringent requirements may be needed to provide additional detection capability. The use of specific radioscopic techniques shall be agreed upon between purchaser and supplier.

1.5 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

E 94 Guide for Radiographic Testing

E 543 Practice for Agencies Performing Nondestructive Testing

E 747 Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E 1000 Guide for Radioscopy

E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E 1255 Practice for Radioscopy

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Standards:*

ASNT Recommended Practice No. SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189-ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Military Standard:*

NAS 410 Certification and Qualification of Nondestructive Personnel

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of terms applicable to this test method may be found in Terminology E 1316.

4. Apparatus

4.1 *Radiation Source (X-Ray or Gamma-Ray)* — Selection of the appropriate source is dependent upon variables regarding the weld being examined, such as material composition and thickness. The suitability of the source shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of the radiation source may be found in Guide E 1000 and Practice E 1255.

4.2 *Manipulation System* — Selection of the appropriate manipulation system (where applicable) is dependent upon variables such as the size and orientation of the object being examined and the range of motions, speed of manipulation, and smoothness of motion. The suitability of the manipulation system shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of the manipulation system may be found in Practice E 1255.

4.3 *Imaging System* — Selection of the appropriate imaging system is dependent upon variables such as the size of the object being examined and the energy and intensity of the radiation used for the examination. The suitability of the imaging system shall be demonstrated by attainment of the required image quality and compliance with all other requirements stipulated herein. Guidance on the selection of an imaging system may be found in Guide E 1000 and Practice E 1255.

4.4 *Image Processing System* — Where agreed between purchaser and supplier, image processing systems may be used for noise reduction through image integration or averaging, contrast enhancement and other image processing operations.

4.5 *Collimation* — Selection of appropriate collimation is dependent upon the geometry of the object being examined. It is generally useful to select collimation to limit the primary radiation beam to the weld and the immediately adjacent base material in order to improve radioscopic image quality.

4.6 *Filters and Masking* — Filters and masking may be used to improve image quality from contrast reductions caused by low-energy scattered radiation. Guidance on the use of filters and masking can be found in Guide E 94.

4.7 *Image Quality Indicators (IQI)* — Unless otherwise specified by the applicable job order or contract, image quality indicators shall comply with the design and identification requirements specified in Practices E 747 or E 1025.

4.8 *Shims, Separate Blocks, or Like Sections* — Shims, separate blocks, or like sections made of the same or radioscopically similar materials (as defined in Practice E 1025) may be used to facilitate image quality indicator positioning as described in 9.10.3. The like section should be geometrically similar to the object being examined.

4.9 *Location and Identification Markers* — Lead numbers and letters should be used to designate the part number and location number. The size and thickness of the markers shall depend on the ability of the radioscopic technique to discern the markers on the images. As a general rule, markers from 0.06 to 0.12 in. (1.5 to 3 mm) thick will suffice for most low energy (less than 1 MeV) X-ray and iridium^{192} radioscopy. For higher energy (greater than 1 MeV and cobalt^{60}) radioscopy, it may be necessary to use markers that are thicker [0.12 in. (3 mm) thick or more]. In cases where the system being used provides a display of object position within the image, this shall be acceptable as identification of object location.

5. Materials

5.1 *Recording Media* — Recording media for storage of images shall be in a format agreed by the purchaser and supplier. This may include either analog or digital media.

6. Basis of Application

6.1 *Personnel Qualification* — NDT personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS 410, or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Testing Agencies* — If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

6.3 *Time of Examination* — The time of examination shall be in accordance with 9.1 unless otherwise specified.

6.4 *Procedures and Techniques* — The procedures and techniques to be utilized shall be as described in this test

method unless otherwise specified. Specific techniques may be specified in the contractual agreement.

6.5 *Extent of Examination* — The extent of examination shall be in accordance with 8.3 unless otherwise specified.

6.6 *Reporting Criteria/Acceptance Criteria* — Reporting criteria for the examination results shall be in accordance with Section 10 unless otherwise specified. Acceptance criteria shall be specified in the contractual agreement.

6.7 *Reexamination of Repaired/Reworked Items* — Reexamination of repaired/reworked items is not addressed in this test method and if required shall be specified in the contractual agreement.

7. Safety

7.1 Radioscopic procedures shall comply with applicable city, state, and federal safety regulations.

8. Requirements

8.1 *Procedure Requirement* — Unless otherwise specified by the applicable job order or contract, radioscopic examination shall be performed in accordance with a written procedure. Specific requirements regarding the preparation and approval of the written procedures shall be as agreed by purchaser and supplier. The production procedure shall address all applicable portions of this test method and shall be available for review during interpretation of the images. The written procedure shall include the following:

8.1.1 Material and thickness range to be examined,

8.1.2 Equipment to be used, including specifications of source parameters (such as tube voltage, current, focal spot size) and imaging equipment parameters (such as detector size, field of view, electronic magnification, camera black level, gain),

8.1.3 Examination geometry, including source-to-object distance, object-to-detector distance and orientation,

8.1.4 Image quality indicator designation and placement,

8.1.5 Test-object scan plan, indicating the range of motions and manipulation speeds through which the test object shall be manipulated in order to ensure satisfactory results (see description in 5.2.1.2 of Practice E 1255),

8.1.6 Image-processing parameters,

8.1.7 Image-display parameters, and

8.1.8 Image storage.

8.2 *Radioscopic Coverage* — Unless otherwise specified by purchaser and supplier agreement, the extent of radioscopic coverage shall include 100% of the volume of the weld and the adjacent base metal.

8.3 *Examination Speed* — For dynamic examination, the speed of object motion relative to the radiation source and detector shall be controlled to ensure that the required radioscopic quality level is achieved.

8.4 *Radioscopic Image Quality* — All images shall be free of marks or other blemishes that could mask or be confused with the image of any discontinuity in the area of interest. It may be possible to prevent blemishes from masking discontinuities or being confused with discontinuities by moving the object being examined relative to the imaging device. If any doubt exists as to the true nature of an indication exhibited in the image, the image shall be rejected and a new image of the area shall be made.

8.5 *Radioscopic Quality Level* — Radioscopic quality level shall be determined upon agreement between the purchaser and supplier and shall be specified in the applicable job order or contract. Radioscopic quality shall be specified in terms of equivalent penetrameter (IQI) sensitivity and shall be measured using image quality indicators conforming to Practices E 747 or E 1025.

8.6 *Acceptance Level* — Accept and reject levels shall be stipulated by the applicable contract, job order, drawing, or other purchaser and supplier agreement.

8.7 *Image-Viewing Facilities* — Viewing facilities shall provide subdued background lighting of an intensity that will not cause troublesome reflection, shadows, or glare on the image.

8.8 *Storage of Images* — When storage is required by the applicable job order or contract, the images should be stored in a format stipulated by the applicable contract, job order, drawing, or other purchaser and supplier agreement. The image-storage duration and location shall be as agreed between purchaser and supplier.

9. Procedure

9.1 *Time of Examination* — Unless otherwise specified by the applicable job order or contract, perform radioscopy prior to heat treatment.

9.2 *Surface Preparation* — Unless otherwise agreed upon, remove the weld bead ripple or weld-surface irregularities on both the inside and outside (where accessible) by any suitable process so that the image of the irregularities cannot mask, or be confused with, the image of any

discontinuity. Interpretation can be optimized if surface irregularities are removed such that the image of the irregularities is not discernible.

9.3 *Source to Detector Distance* — Unless otherwise specified in the applicable job order or contract, geometric unsharpness (U_g) shall not exceed the following:

Material Thickness	U_g, max, in. (mm)
under 2 in. (50 mm)	0.020 (0.50)
2 through 3 in. (50 through 75 mm)	0.030 (0.75)
over 3 through 4 in. (75 through 100 mm)	0.040 (1.00)
greater than 4 in. (100 mm)	0.070 (1.75)

Determine geometric unsharpness values as specified in Guide E 94.

9.4 *Examination Speed* — For dynamic examination, determine the speed of object motion relative to the radiation source and detector upon agreement between the purchaser and supplier. Base this determination upon the achievement of the required radioscopic quality level at that examination speed.

9.5 *Direction of the Radiation* — Direct the central beam of radiation perpendicularly toward the center of the effective area of the detector or to a plane tangent to the center of the image, to the maximum extent possible, except for double-wall exposure-double-wall viewing elliptical projection techniques, as described in 9.14.2.

9.6 *Scattered Radiation* — Scattered radiation (radiation scattered from the test object and from surrounding structures) reduces radioscopic contrast and may produce undesirable effects on radioscopic quality. Use precautions such as collimation of the source, collimation of the detector, and additional shielding as appropriate to minimize the detrimental effects of this scattered radiation.

9.7 *Image Quality Indicator Selection* — For selection of the image quality indicator, the thickness on which the image quality indicator is based is the single-wall thickness plus the lesser of the actual or allowable reinforcement. Backing strips or rings are not considered as part of the weld or reinforcement thickness for image quality indicator selection. For any thickness, an image quality indicator acceptable for thinner materials may be used, provided all other requirements for radioscopy are met.

9.8 *Number of Image Quality Indicators:*

9.8.1 Place at least one image quality indicator (Practices E 747 or E 1025) in the area of interest representing an area in which the brightness is relatively uniform. The degree of brightness uniformity shall be agreed upon between purchaser and supplier. If the image brightness in an area of interest differs by more than the agreed amount, use two image quality indicators. Use one image quality indicator to demonstrate acceptable image quality in the darkest portion of the image and use one image quality indicator to demonstrate acceptable image quality in the lightest portion of the image.

9.8.2 When a series of images are made under identical conditions, it is permissible for the image quality indicators to be used only on the first and last images in the series, provided this is agreed upon between the purchaser and supplier. In this case, it is not necessary for the image quality indicators to appear in each image.

9.8.3 Always retain qualifying images, on which one or more image quality indicators were imaged during exposure, as part of the record to validate the required image quality indicator sensitivity and placement.

9.9 *Image Quality Indicator Placement:*

9.9.1 Place the image quality indicator on the source side adjacent to the weld being examined. Where the weld metal is not radioscopically similar to the base material or where geometry precludes placement adjacent to the weld, place the image quality indicator over the weld or on a separate block, as described in 9.10.

9.9.2 *Detector-Side Image Quality Indicators* — In those cases where the physical placement of the image quality indicators on the source side is not possible, place the image quality indicators on the detector side. The applicable job order or contract shall specify the applicable detector-side quality level. The accompanying documents shall clearly indicate that the image quality indicators were located on the detector side.

9.10 *Separate Block* — When configuration or size prevents placing the image quality indicators on the object being examined, use a shim, separate block or like section conforming to the requirements of 4.8 provided the following conditions are met:

9.10.1 The image quality indicator is no closer to the detector than the source side of the object being examined (unless otherwise specified).

9.10.2 The radioscopic brightness in the area of the image quality indicator including the shim, separate block, or like section and IQI where applicable are similar to the brightness in the area of interest.

9.10.3 The shim, separate block, or like section is placed as close as possible to the object being examined.

9.10.4 When hole-type image quality indicators are used, the shim, separate block, or like section dimensions shall exceed the image quality indicator dimensions such

that the outline of at least three sides of the image quality indicator image is visible on the image.

9.11 *Shim Utilization* — When a weld reinforcement or backing ring and strip is not removed, place a shim of material that is radioscopically similar to the backing ring and strip under the image quality indicators to provide approximately the same thickness of material under the image quality indicator as the average thickness of the weld reinforcement plus the wall thickness, backing ring and strip.

9.11.1 *Shim Dimensions and Location* — When hole-type image quality indicators are used, the shim dimensions and location shall exceed the image quality indicator dimensions by at least 0.12 in. (3 mm) on at least three sides. At least three sides of the image quality indicator shall be discernible in accordance with 9.10.4 except that only the two ends of the image quality indicator need to be discernible when located on piping less than 1 in. (25 mm) nominal pipe size. Place the shim so as not to overlap the weld image including the backing strip or ring.

9.11.2 *Shim Image Brightness* — The image brightness of the shim image shall be similar to the image brightness of the area of interest.

9.12 *Location Markers* — Place location markers outside the weld area. The radioscopic image of the location markers for the identification of the part location with the image shall appear on the image without interfering with the interpretation and with such an arrangement that it is evident that complete coverage was obtained.

9.12.1 *Double-Wall Technique* — When using a technique in which radiation passes through two walls and the welds in both walls are simultaneously viewed for acceptance, and the entire image of the object being examined is displayed, only one location marker is required in the image.

9.12.2 *Series of Images* — For welds that require a series of images to cover the full length or circumference of the weld, apply the complete set of location markers at one time, wherever possible. A reference or zero position for each series must be identified on the component. A known feature on the object (for example, keyway, nozzle, and axis line) may also be used for establishment of a reference position. Indicate this feature on the radioscopic record.

9.12.3 *Similar Welds* — On similar type welds on a single component, the sequence and spacing of the location markers must conform to a uniform system that shall be positively identified in the radioscopic procedure or interpretation records. In addition, reference points on the component will be shown on the sketch to indicate the direction of the numbering system.

9.13 *Image Identification* — Provide a system of positive identification of the image. As a minimum, the following shall appear on the image: the name or symbol of the company performing radioscopy, the date, and the weld identification number traceable to part and contract. Identify subsequent images made of a repaired area with the letter "R."

9.14 *Radioscopic Techniques:*

9.14.1 *Single-Wall Technique* — Except as provided in 9.14.2, 9.14.3, and 9.14.4, perform radioscopy using a technique in which the radiation passes through only one wall.

9.14.2 *Double-Wall Technique for Circumferential Welds* — For circumferential welds 4 in. (100 mm) outside diameter (3.5 in. nominal pipe size) or less, use a technique in which the radiation passes through both walls and both walls are viewed for acceptance on the same image. Unless otherwise specified, either elliptical or superimposed projections may be used. A sufficient number of views should be taken to examine the entire weld. Where design or access restricts a practical technique from examining the entire weld, agreement between contracting parties must specify necessary weld coverage.

9.14.3 For circumferential welds greater than 4 in. (100 mm) outside diameter (3.5 in. nominal pipe size), use a technique in which only single-wall viewing is performed. A sufficient number of views should be taken to examine the entire weld. Where design or access restricts a practical technique from examining the entire weld, agreement between contracting parties must specify necessary weld coverage.

9.14.4 For radioscopic techniques that prevent single-wall exposures due to restricted access, such as jacketed pipe or ship hull, the technique should be agreed upon in advance between the purchaser and supplier. It should be recognized that image quality indicator sensitivities based on single-wall thickness may not be obtainable under some conditions.

10. Records

10.1 Maintain the following radioscopic records as agreed between purchaser and supplier:

10.1.1 Radioscopic standard shooting sketch, including examination geometry, source-to-object distance, object-to-detector distance and orientation,

10.1.2 Material and thickness range examined,

10.1.3 Equipment used, including specification of source parameters (such as tube voltage, current, focal

spot size) and imaging equipment parameters (such as detector size, field of view, electronic magnification, camera blacklevel, gain, etc.) and display parameters,

10.1.4 Image quality indicator (and shim, if used) placement,

10.1.5 Test-object scan plan, including ranges of motion and manipulation speeds,

10.1.6 Image processing parameters,

10.1.7 Image-storage data,

10.1.8 Weld repair documentation, and

10.1.9 *Image* — Interpretation record shall contain as a minimum the following information:

10.1.9.1 Disposition of each image (acceptable or rejectable),

10.1.9.2 If rejectable, cause for rejection (slag, crack, porosity, etc.),

10.1.9.3 Surface indication verified by visual examination (grinding marks, weld ripple, spatter, etc.), and

10.1.9.4 Signature of the image interpreter, including level.

11. Precision and Bias

11.1 No statement is made about either precision or bias of this test method since the result merely states whether there is conformance to the criteria of success specified in the procedure.

12. Keywords

12.1 gamma ray; nondestructive testing; radioscopic examination; radioscopy; weldments; X-ray

A06

STANDARD PRACTICE FOR DETERMINING CONTRAST SENSITIVITY IN RADIOLOGY

SE-1647

(Identical with ASTM Specification E 1647-03.)

1. Scope

1.1 This practice covers the design and material selection of a contrast sensitivity measuring gage used to determine the minimum change in material thickness or density that may be imaged without regard to spatial resolution limitations.

1.2 This practice is applicable to transmitted-beam radiographic and radioscopic imaging systems utilizing X-ray and gamma ray radiation sources.

1.3 The values stated in inch-pound units are to be regarded as standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific safety statements, see NIST/ ANSI Handbook 114 Section 8, Code of Federal Regulations 21 CFR 1020.40 and 29 CFR 1910.96.

2. Referenced Documents

2.1 *ASTM Standards:*

B 139 Specification for Phosphor Bronze Rod, Bar, and Shapes

B 150 Specification for Aluminum Bronze Rod, Bar, and Shapes

B 161 Specification for Nickel Seamless Pipe and Tube

B 164 Specification for Nickel-Copper Alloy Rod, Bar, and Wire

B 166 Specification for Nickel-Chromium-Iron Alloys (UNS N06600, N06601, and N06690) and Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617) Rod, Bar, and Wire

E 747 Practice for the Design Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used For Radiology

E 1025 Practice for Hole-Type Image Quality Indicators Used for Radiography

E 1316 Terminology for Nondestructive Examination

E 1411 Practice for Qualification of Radioscopic Systems

E 2002 Practice for Determining Total Image Unsharpness in Radiology

21 CFR 1020.40 Safety Requirements for Cabinet X-ray Systems

29 CFR 1910.96 Ionizing Radiation

2.3 *NIST/ANSI Standard:*

NIST/ANSI Handbook 114 General Safety Standard for Installations Using Non-Medical X-ray and Sealed Gamma Ray Sources, Energies to 10 MeV

2.4 *Other Standards:*

EN 462-5 Duplex Wire Image Quality Indicator

EN 13068-1 Radioscopic Testing — Part 1: Qualitative Measurement of Imaging Properties

3. Terminology

3.1 *Definitions* — Definitions of terms applicable to this test method may be found in Terminology E 1316.

4. Summary of Practice

4.1 It is often useful to evaluate the contrast sensitivity of a penetrating radiation imaging system separate and apart from spatial resolution measurements. Conventional image quality indicators (IQIs), such as Test Method E

747 wire and Practice E 1025 plaque IQIs, combine the contrast sensitivity and resolution measurements into an overall performance figure of merit, other methods such as included in Practice E 2002 do not address contrast specifically. Such figures of merit are often not adequate to detect subtle changes in imaging system performance. For example, in a high contrast image, spatial resolution can degrade with almost no noticeable effect upon overall image quality. Similarly, in an application in which the imaging system provides a very sharp image, contrast can fade with little noticeable effect upon the overall image quality. These situations often develop and may go unnoticed until the system performance deteriorates below acceptable image quality limits.

5. Significance and Use

5.1 The contrast sensitivity gage measures contrast sensitivity independent of the imaging system spatial resolution limitations. The thickness recess dimensions of the contrast sensitivity gage are large with respect to the spatial resolution limitations of most imaging systems. Four levels of contrast sensitivity are measured: 4%, 3%, 2%, and 1%.

5.2 The contrast sensitivity gage is intended for use in conjunction with a high-contrast resolution measuring gage, such as the EN 462-5 Duplex Wire Image Quality Indicator. Such gages measure spatial resolution essentially independent of the imaging system's contrast sensitivity. Such measurements are appropriate for the qualification and performance monitoring of radiographic and radioscopic imaging systems.

5.3 Radioscopic/radiographic system performance may be specified by combining the measured contrast sensitivity expressed as a percentage with the spatial resolution expressed in millimeters of unsharpness. For the EN 462-5 spatial resolution gage, the unsharpness is equal to twice the wire diameter. For the line pair gage, the unsharpness is equal to the reciprocal of the line-pair/mm value. As an example, an imaging system that exhibits 2% contrast sensitivity and images the 0.1 mm EN 462-5 paired wires (equivalent to imaging 5 line-pairs/millimeter resolution on a line-pair gage) performs at a 2%–0.2 mm sensitivity level. A standard method of evaluating overall radioscopic system performance is given in Practice E 1411 and in EN 13068-1.

6. Contrast Sensitivity Gage Construction and Material Selection

6.1 Contrast sensitivity gages shall be fabricated in accordance with Fig. 1, using the dimensions given in Tables 1, 2, and 3.

6.2 The gage shall preferably be fabricated from the test object material. Otherwise, the following material selection guidelines are to be used:

6.2.1 Materials are designated in eight groupings, in accordance with their penetrating radiation absorption characteristics: groups 03, 02, and 01 for light metals and groups 1 through 5 for heavy metals.

6.2.2 The light metal groups, magnesium (Mg), aluminum (Al), and titanium (Ti), are identified 03, 02, and 01, respectively, for their predominant constituent. The materials are listed in order of increasing radiation absorption.

6.2.3 The heavy metals group, steel, copper base, nickel base, and other alloys, are identified 1 through 5. The materials increase in radiation absorption with increasing numerical designation.

6.2.4 Common trade names or alloy designations have been used for clarification of pertinent materials.

6.3 The materials from which the contrast sensitivity gage is to be made is designated by group number. The gage is applicable to all materials in that group. Material groupings are as follows:

6.3.1 *Material Group 03:*

6.3.1.1 The gage shall be made of magnesium or a magnesium alloy, provided it is no more radio-opaque than unalloyed magnesium, as determined by the method outlined in 6.4.

6.3.1.2 Use for all alloys where magnesium is the predominant alloying constituent.

6.3.2 *Materials Group 02:*

6.3.2.1 The gage shall be made of aluminum or an aluminum alloy, provided it is no more radio-opaque than unalloyed aluminum, as determined by the method outlined in 6.4.

6.3.2.2 Use for all alloys where aluminum is the predominant alloying constituent.

6.3.3 *Materials Group 01:*

6.3.3.1 The gage shall be made of titanium or a titanium alloy, provided it is no more radio-opaque than unalloyed titanium, as determined by the method outlined in 6.4.

6.3.3.2 Use for all alloys where titanium is the predominant alloying constituent.

6.3.4 *Materials Group 1:*

6.3.4.1 The gage shall be made of carbon steel or Type 300 series stainless steel.

6.3.4.2 Use for all carbon steel, low-alloy steels, stainless steels, and magnesium-nickel-aluminum bronze (Superston).

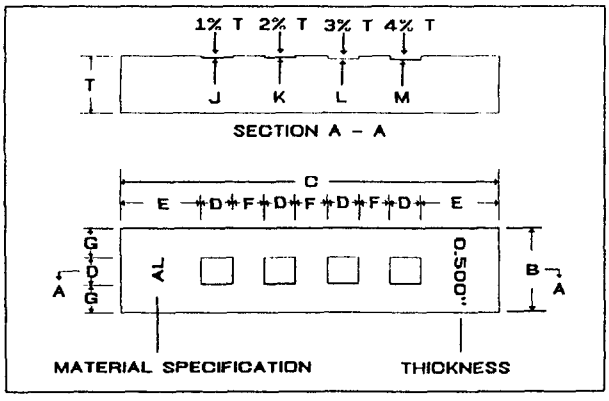


FIG. 1 GENERAL LAYOUT OF THE CONTRAST SENSITIVITY GAGE

TABLE 1
DESIGN OF THE CONTRAST SENSITIVITY GAGE

Gage Thickness	J Recess	K Recess	L Recess	M Recess
T	1% of T	2% of T	3% of T	4% of T

TABLE 2
CONTRAST SENSITIVITY GAGE DIMENSIONS

Gage Size	B DIM.	C DIM.	D DIM.	E DIM.	F,G DIM.
1	0.750 in.	3.000 in.	0.250 in.	0.625 in.	0.250 in.
	19.05 mm	76.20 mm	6.35 mm	15.88 mm	6.35 mm
2	1.500 in.	6.000 in.	0.500 in.	1.250 in.	0.500 in.
	38.10 mm	152.40 mm	12.70 mm	31.75 mm	12.7 mm
3	2.250 in.	9.000 in.	0.750 in.	1.875 in.	0.750 in.
	57.15 mm	228.60 mm	19.05 mm	47.63 mm	19.05 mm
4	3.000 in.	12.000 in.	1.000 in.	2.500 in.	1.000 in.
	76.20 mm	304.80 mm	25.40 mm	63.50 mm	25.4 mm

TABLE 3
CONTRAST SENSITIVITY GAGE APPLICATION

Gage Size	Use on Thicknesses
1	Up to 1.5 in. (38.1 mm)
2	Over 1.5 in. (38.1 mm) to 3.0 in. (76.2 mm)
3	Over 3.0 in. (76.2 mm) to 6.0 in. (152.4 mm)
4	Over 6.0 in. (152.4 mm)

6.3.5 *Materials Group 2:*

6.3.5.1 The gage shall be made of aluminum bronze (Alloy No. 623 of Specification B 150) or equivalent or nickel-aluminum bronze (Alloy No. 630 of Specification B 150) or equivalent.

6.3.5.2 Use for all aluminum bronzes and all nickel aluminum bronzes.

6.3.6 *Materials Group 3:*

6.3.6.1 The gage shall be made of nickel-chromium-iron alloy (UNS No. N06600) (Inconel). See Specification B 166.

6.3.6.2 Use for nickel-chromium-iron alloy and 18% nickel-maraging steel.

6.3.7 *Materials Group 4:*

6.3.7.1 The gage shall be made of 70 to 30 nickel-copper alloy (Monel) (Class A or B of Specification B 164) or equivalent, or 70 to 30 copper-nickel alloy (Alloy G of Specification B 161) or equivalent.

6.3.7.2 Use for nickel, copper, all nickel-copper series or copper-nickel series of alloys and all brasses (copper-zinc alloys) and all leaded brasses.

6.3.8 *Materials Group 5:*

6.3.8.1 The gage shall be made of tin-bronze (Alloy D of Specification B 139).

6.3.8.2 Use for tin bronzes including gun-metal and valve bronze and leaded-tin bronzes.

6.4 Where the material to be examined is a composite, ceramic, or other nonmetallic material, or for some reason cannot be obtained to fabricate a gage, an equivalent material may be utilized, provided it is no more radio-opaque than the examination object under comparable penetrating radiation energy conditions. To determine the suitability of a substitute material, radiograph identical thicknesses of both materials on one film using the lowest penetrating radiation energy to be used in the actual examination. Transmission densitometer readings for both materials shall be in the range from 2.0 to 4.0. If the radiographic density of the substitute material is within +15% to −0% of the examination material, the substitute material is acceptable.

6.4.1 All contrast sensitivity gages shall be suitably marked by vibro-engraving or etching. The gage thickness and material type shall be clearly marked.

7. Imaging System Performance Levels

7.1 Imaging system performance levels are designated by a two-part measurement expressed as C(%) — U(mm). The first part of the expression C(%) refers to the depth of the shallowest flat-bottom hole that can be reliably and repeatably imaged. The second part of the expression refers to the companion spatial resolution measurement made with a resolution gage expressed in terms of millimeters unsharpness. Where contrast sensitivity is measured for both thin and thick section performance, the performance level is expressed as C_{min} (%)–C_{max}(%)–U(mm).

7.2 Each contrast sensitivity gage has four flat-bottom recesses that represent 1%, 2%, 3%, and 4% of the gage total thickness. The shallowest recess that can be repeatably and reliably imaged shall determine the limiting contrast sensitivity.

7.3 Contrast sensitivity measurements shall be made under conditions as nearly identical to the actual examination as possible. Penetrating radiation energy, image formation, processing, analysis, display, and viewing variables shall accurately simulate the actual examination environment.

8. Contrast Sensitivity Gage Measurement Steps (see Table 1)

8.1 The gage thickness T shall be within ±5% of the examination object thickness value at which contrast sensitivity is being determined.

8.2 The gage thickness tolerance shall be within ±1% of the gage design thickness T or 0.001 in. (0.02 mm), whichever is greater.

8.3 The gage recess depth tolerance shall be within ±10% of the design value for the shallowest recess or 0.001 in. (0.02 mm), whichever is greater.

8.4 The gage recess inside and outside corner radius shall not exceed 0.062 in. (1.80 mm). To facilitate fabrication, the gage may be assembled from three individually machined components: (*1*) the machined center section containing the 1% T, 2% T, 3% T, and 4% T milled slots; (*2*) the front rail, and (*3*) the rear rail. The assemblage of the three components forms the complete gage similar to that shown in Appendix X1.

8.5 The gage dimensional tolerances shall be held to within ±0.010 in. (0.25 mm) of the dimensions specified in Table 2.

9. Acceptable Performance Levels

9.1 Nothing in this practice implies a mandatory or an acceptable contrast sensitivity performance level. That determination is to be agreed upon between the supplier and user of penetrating radiation examination services.

9.2 The recess depths specified in Table 1 provide measurement points at 1%, 2%, 3%, and 4% that will accommodate many imaging system configurations. Other contrast sensitivity measurement points may be obtained by placing the gage on a shim made of the gage material. The resulting contrast sensitivity measurement expressed as a percentage is given by the following formula:

$$\% \text{ Contrast} = \frac{R}{T + S} \times 100$$

where:

R = recess depth,
S = shim thickness, and
T = gage thickness.

If other recess depths are required to document radioscopic or radiographic system performance, special contrast sensitivity gages may be fabricated by changing the recess depths specified in Table 1 to suit the need.

10. Performance Measurement Records

10.1 The results of the contrast sensitivity measurement should be recorded and maintained as a part of the initial qualification and performance monitoring records for the imaging system. Changes in contrast sensitivity can be an early indicator of deteriorating imaging system performance.

11. Precision and Bias

11.1 No statement is made about the precision or bias for indicating the contrast sensitivity of a radiologic (radiographic or radioscopic) system using the contrast sensitivity gage described by this practice.

12. Keywords

12.1 contrast sensitivity gage; gamma ray; image formation; image processing; image quality indicator; line-pairs per millimeter; penetrating radiation; spatial resolution; X-ray

APPENDIX

(Nonmandatory Information)

X1. ASSEMBLING THE CONTRAST SENSITIVITY GAGE

X1.1 Suggested method of assembling the contrast sensitivity gage from a milled center section with front and rear rails attached to form the complete contrast sensitivity gage. The example shown (see Fig. X1.1) is for use with a 0.500 in. thick examination object.

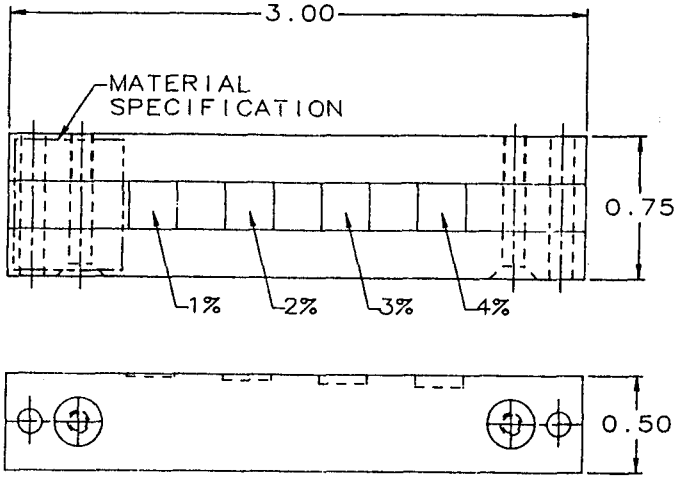


FIG. X1.1 CONTRAST SENSITIVITY GAGE

ARTICLE 23
ULTRASONIC STANDARDS

SPECIFICATION FOR ULTRASONIC EXAMINATION OF HEAVY STEEL FORGINGS

A06

SA-388/SA-388M

(Identical with ASTM Specification A 388/A 388M-04)

1. Scope

1.1 This practice covers the examination procedures for the contact, pulse-echo ultrasonic examination of heavy steel forgings by the straight- and angle-beam techniques. The straight-beam techniques include utilization of the DGS (Distance Gain Size) method. See Appendix X3.

1.2 This practice is to be used whenever the inquiry, contract, order, or specification states that forgings are to be subject to ultrasonic examination in accordance with Practice A 388/A 388M.

1.3 The values stated in either inch-pound or SI units are to be regarded as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 This specification and the applicable material specifications are expressed in both inch-pound units and SI units. However, unless the order specifies the applicable "M" specification designation (SI units), the material shall be furnished to inch-pound units.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 469 Specification for Vacuum-Treated Steel Forgings for Generator Rotors

A 745/A 745M Practice for Ultrasonic Examination of Austenitic Steel Forgings

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Examination Instruments and Systems Without the Use of Electronic Measurement Instruments

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection

2.2 *ANSI Standard:*

B46.1 Surface Texture

2.3 *Other Document:*

Recommended Practice for Nondestructive Personnel Qualification and Certification SNT-TC-1A, Supplement C — Ultrasonic Testing

3. Ordering Information

3.1 When this practice is to be applied to an inquiry, contract, or order, the purchaser shall so state and shall also furnish the following information:

3.1.1 Method of establishing the sensitivity in accordance with 7.2.2 and 7.3.3 (Vee or rectangular notch),

3.1.1.1 The diameter and test metal distance of the flat-bottom hole and the material of the reference block in accordance with 7.2.2.2,

3.1.2 Quality level for the entire forging or portions thereof in accordance with 10.3, and

3.1.3 Any options in accordance with 6.1, 6.2, and 7.1.11.

4. Apparatus

4.1 An ultrasonic, pulsed, reflection type of instrument shall be used for this examination. The system shall have a minimum capability for examining at frequencies from 1 to 5 MHz. On examining austenitic stainless forgings the system shall have the capabilities for examining at frequencies down to 0.4 MHz.

4.1.1 The ultrasonic instrument shall provide linear presentation (within 5%) for at least 75% of the screen height (sweep line to top of screen). The 5% linearity referred to is descriptive of the screen presentation of amplitude. Instrument linearity shall be verified in accordance with the intent of Practice E 317. Any set of blocks processed in accordance with Practice E 317 or E 428 may be used to establish the specified ± 5% instrument linearity.

4.1.2 The electronic apparatus shall contain an attenuator [accurate over its useful range to ± 10% (± 1 dB) of the amplitude ratio] which will allow measurement of indications beyond the linear range of the instrument.

4.2 *Search Units* having a transducer with a maximum active area of 1 in.^{2} [650 mm^2] with $^3/_4$ in. [20 mm] minimum to $1^1/_8$ in. [30 mm] maximum dimensions shall be used for straight-beam scanning (see 7.2); and search units equipped from $^1/_2$ by 1 in. [13 by 25 mm] to 1 by 1 in. [25 by 25 mm] shall be used for angle-beam scanning (see 7.3).

4.2.1 *Transducers* shall be utilized at their rated frequencies.

4.2.2 Other search units may be used for evaluating and pinpointing indications.

4.3 *Couplants* having good wetting characteristics such as SAE No. 20 or No. 30 motor oil, glycerin, pine oil, or water shall be used. Couplants may not be comparable to one another and the same couplant shall be used for calibration and examination.

4.4 *Reference Blocks* containing flat-bottom holes may be used for calibration of equipment in accordance with 4.1.1 and may be used to establish recording levels for straight-beam examination when so specified by the order or contract.

4.5 *DGS scales,* matched to the ultrasonic test unit and transducer to be utilized, may be used to establish recording levels for straight-beam examination, when so specified by the order or contract. The DGS scale range must be selected to include the full thickness cross-section of the forging to be examined. An example of a DGS overlay is found in Appendix X3.

5. Personnel Requirements

5.1 Personnel performing the ultrasonic examinations to this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard that is acceptable to both the purchaser and the supplier.

6. Preparation of Forging for Ultrasonic Examination

6.1 Unless otherwise specified in the order or contract, the forging shall be machined to provide cylindrical surfaces for radial examination in the case of round forgings; the ends of the forgings shall be machined perpendicular to the axis of the forging for the axial examination. Faces of disk and rectangular forgings shall be machined flat and parallel to one another.

6.2 The surface roughness of exterior finishes shall not exceed 250 μin. [6 μm] unless otherwise shown on the forging drawing or stated in the order or the contract.

6.3 The surfaces of the forging to be examined shall be free of extraneous material such as loose scale, paint, dirt, etc.

7. Procedure

7.1 *General:*

7.1.1 As far as practicable, subject the entire volume of the forging to ultrasonic examination. Because of radii at change of sections and other local configurations, it may be impossible to examine some sections of a forging.

7.1.2 Perform the ultrasonic examination after heat treatment for mechanical properties (exclusive of stress-relief treatments) but prior to drilling holes, cutting keyways, tapers, grooves, or machining sections to contour. If the configuration of the forging required for the treatment for mechanical properties prohibits a subsequent complete examination of the forging, it shall be permissible to examine prior to treatment for mechanical properties. In such cases, reexamine the forging ultrasonically as completely as possible after heat treatment.

7.1.3 To ensure complete coverage of the forging volume, index the search unit with at least 15% overlap with each pass.

7.1.4 For manual scanning, do not exceed a scanning rate of 6 in./s [150 mm/s].

7.1.5 For automated scanning, adjust scanning speed or instrument repetition rate, or both, to permit detection of the smallest discontinuities referenced in the specification and to allow the recording or signaling device to function. At no time shall the scanning speed exceed the speed at which an acceptable calibration was made.

7.1.6 If possible, scan all sections of forgings in two perpendicular directions.

7.1.7 Scan disk forgings using a straight-beam technique from at least one flat face and radially from the circumference, whenever practicable.

7.1.8 Scan cylindrical sections and hollow forgings radially using a straight beam. When practicable, also examine the forging in the axial direction.

7.1.9 In addition, examine hollow forgings by angle-beam technique from the outside diameter surface as required in 7.3.1.

7.1.10 In rechecking or reevaluation by manufacturer or purchaser use comparable equipment, search units, frequency, and couplant.

7.1.11 Forgings may be examined either stationary or while rotating in a lathe or on rollers. If not specified by the purchaser, either method may be used at the manufacturer's option.

7.2 *Straight-Beam Examination:*

7.2.1 For straight-beam examination use a nominal $2\frac{1}{4}$-MHz search unit whenever practicable; however, 1 MHz is the preferred frequency for coarse grained austenitic materials and long testing distances. In many instances on examining coarse grained austenitic materials it may be necessary to use a frequency of 0.4 MHz. Other frequencies may be used if desirable for better resolution, penetrability, or detectability of flaws.

7.2.2 Establish the instrument sensitivity by either the reflection, reference-block technique, or DGS method (see Appendix X3 for an explanation of the DGS method).

7.2.2.1 *Back-Reflection Technique (Back-Reflection Calibration Applicable to Forgings with Parallel Entry and Back Surfaces)* — With the attenuator set at an appropriate level, for example 5 to 1 or 14 dB, adjust the instrument controls to obtain a back reflection approximately 75% of the full-screen height from the opposite side of the forging. Scan the forging at the maximum amplification setting of the attenuator (attenuator set at 1 to 1). Carry out the evaluation of discontinuities with the gain control set at the reference level. Recalibration is required for significant changes in section thickness or diameter.

NOTE 1 — High sensitivity levels are not usually employed when inspecting austenitic steel forgings, due to attendant high level of "noise" or "hash" caused by coarse grain structure.

7.2.2.2 *Reference-Block Calibration* — The test surface roughness on the calibration standard shall be comparable to but no better than the item to be examined. Adjust the instrument controls to obtain the required signal amplitude from the flat-bottom hole in the specified reference block. Utilize the attenuator in order to set up on amplitudes larger than the vertical linearity of the instrument. In those cases, remove the attenuation prior to scanning the forging.

NOTE 2 — When flat-surfaced reference block calibration is specified, adjust the amplitude of indication from the reference block or blocks to compensate for examination surface curvature (an example is given in Appendix X1).

7.2.2.3 *DGS Calibration* — Prior to use, verify that the DGS overlay matches the transducer size and frequency. Accuracy of the overlay can be verified by reference blocks and procedures outlined in Practice E 317. Overlays are to be serialized to match the ultrasonic transducer and pulse-echo testing system that they are to be utilized with.

7.2.2.4 Choose the appropriate DGS scale for the cross-sectional thickness of the forging to be examined. Insert the overlay over the CRT screen, ensuring the DGS scale baseline coincides with the sweep line of the CRT screen. Place the probe on the forging, adjust the gain to make the first backwall echo appear clearly on the CRT screen. Using the Delay and Sweep control, shift the screen pattern so that the leading edge of the initial pulse is on zero of the DGS scale and the backwall echo is on the DGS scale value corresponding to the thickness of the forging. Adjust the gain so the forging backwall echo matches the height of the DGS reference slope within ± 1 Db. Once adjusted, increase the gain by the Db shown

on the DGS scale for the reference slope. Instrument is now calibrated and flaw sizes that can be reliably detected can be directly read from the CRT screen. These flaw sizes are the equivalent flat bottom reflector that can be used as a reference point.

NOTE 3 — The above can be utilized on all solid forgings. Cylindrical hollow forgings and drilled or bored forgings must be corrected to compensate for attenuation due to the central hole (see Appendix X4).

7.2.3 *Recalibration* — Any change in the search unit, couplant, instrument setting, or scanning speed from that used for calibration shall require recalibration. Perform a calibration check at least once every 8 h shift. When a loss of 15% or greater in the gain level is indicated, reestablish the required calibration and reexamine all of the material examined in the preceding calibration period. When an increase of 15% or greater in the gain level is indicated, reevaluate all recorded indications.

7.2.4 During the examination of the forging, monitor the back reflection for any significant reduction in amplitude. Reduction in back-reflection amplitude may indicate not only the presence of a discontinuity but also poor coupling of the search unit with the surface of the forging, nonparallel back-reflection surface, or local variations of attenuation in the forging. Recheck any areas causing loss of back reflection.

7.3 *Angle-Beam Examination — Rings and Hollow Forgings:*

7.3.1 Perform the examination from the circumference of rings and hollow forgings that have an axial length greater than 2 in. [50 mm] and an outside to inside diameter ratio of less than 2.0 to 1.

7.3.2 Use a 1 MHz, 45 deg angle-beam search unit unless thickness, OD/ID ratio, or other geometric configuration results in failure to achieve calibration. Other frequencies may be used if desirable for better resolution, penetrability, or detectability of flaws. For angle-beam inspection of hollow forgings up to 2.0 to 1 ratio, provide the transducer with a wedge or shoe that will result in the beam mode and angle required by the size and shape of the cross section under examination.

7.3.3 Calibrate the instrument for the angle-beam examination to obtain an indication amplitude of approximately 75% full-screen height from a rectangular or a 60 deg V-notch on inside diameter (ID) in the axial direction and parallel to the axis of the forging. A separate calibration standard may be used; however, it shall have the same nominal composition, heat treatment, and thickness as the forging it represents. The test surface finish on the calibration standard shall be comparable but no better than the item to be examined. Where a group of identical forgings is made, one of these forgings may be used as the separate calibration standard. Cut the ID notch depth to 3% maximum of the thickness or $^1/_4$ in. [6 mm], whichever is smaller, and its length approximately 1 in. [25 mm]. Thickness is defined as the thickness of the forging to be examined at the time of examination. At the same instrument setting, obtain a reflection from a similar OD notch. Draw a line through the peaks of the first reflections obtained from the ID and OD notches. This shall be the amplitude reference line. It is preferable to have the notches in excess metal or test metal when possible. When the OD notch cannot be detected when examining the OD surface, perform the examination when practicable (some IDs may be too small to permit examination) as indicated above from both the OD and ID surfaces. Utilize the ID notch when inspecting from the OD, and the OD notch when inspecting from the ID. Curve wedges or shoes may be used when necessary and practicable.

7.3.4 Perform the examination by scanning over the entire surface area circumferentially in both the clockwise and counter-clockwise directions from the OD surface. Examine forgings, which cannot be examined axially using a straight beam, in both axial directions with an angle-beam search unit. For axial scanning, use rectangular or 60 deg V-notches on the ID and OD for the calibration. These notches shall be perpendicular to the axis of the forging and the same dimensions as the axial notch.

8. Recording

8.1 *Straight-Beam Examination* — Record the following indications as information for the purchaser. These recordable indications do not constitute a rejectable condition unless negotiated as such in the purchase order.

8.1.1 In the back-reflection technique, individual indications equal to or exceeding 10% of the back reflection from an adjacent area free from indications; in the reference-block or DGS technique, indications equal to or exceeding 100% of the reference amplitude.

8.1.2 An indication that is continuous on the same plane regardless of amplitude, and found over an area larger than twice the diameter of the search unit. The extent of such an indication shall be accurately measured along with variations in amplitudes of reflections.

8.1.2.1 Planar indications shall be considered continuous over a plane if they have a major axis greater than 1 in. [25 mm]. In recording these indications, corrections must be made for beam divergence at the estimated flaw depth.

8.1.3 In the back-reflection technique, discontinuity indications equal to or exceeding 5% of the back reflection. In the reference-block technique, indications equal

to or exceeding 50% of the reference amplitude providing that they travel, are continuous, or appear as clusters.

8.1.3.1 Traveling indications are herein defined as indications whose leading edge moves a distance equivalent to 1 in. [25 mm] or more of metal depth with movement of the search unit over the surface of the forging.

8.1.3.2 A cluster of indications is defined as five or more indications located in a volume representing a 2-in. [50-mm] or smaller cube in the forging.

8.1.4 Reduction in back reflection exceeding 20% of the original measured in increments of 10%.

8.1.5 Amplitudes of recordable indications in increments of 10%.

8.2 *Angle-Beam Examination* — Record discontinuity indications equal to or exceeding 50% of the indication from the reference line. When an amplitude reference line cannot be generated, record discontinuity indications equal to or exceeding 50% of the reference notch. These recordable indications do not constitute a rejectable condition unless negotiated as such in the purchase order.

9. Report

9.1 Report the following information:

9.1.1 All recordable indications (see Section 8).

9.1.2 For the purpose of reporting the locations of recordable indications, a sketch shall be prepared showing the physical outline of the forging including dimensions of all areas not inspected due to geometric configuration, the purchaser's drawing number, the purchaser's order number, and the manufacturer's serial number, and the axial, radial, and circumferential distribution of recordable ultrasonic indications.

9.1.3 The specification to which the examination was performed as well as the frequency used, method of setting sensitivity, type of instrument, surface finish, couplant, and search unit employed.

9.1.4 The inspector's name or identity and date the examination was performed.

10. Quality Levels

10.1 This practice is intended for application to forgings, with a wide variety of sizes, shapes, compositions, melting processes, and applications. It is, therefore, impracticable to specify an ultrasonic quality level which would be universally applicable to such a diversity of products. Ultrasonic acceptance or rejection criteria for individual forgings should be based on a realistic appraisal of service requirements and the quality that can normally be obtained in the production of the particular type forging.

10.2 Heavy austenitic stainless steel forgings are more difficult to penetrate ultrasonically than similar carbon or low-alloy steel forgings. The degree of attenuation normally increases with section size; and the noise level, generally or in isolated areas, may become too great to permit detection of discrete indications. In most instances, this attenuation results from inherent coarse grained microstructure of these austenitic alloys. For these reasons, the methods and standards employed for ultrasonically examining carbon and low-alloy steel forgings may not be applicable to heavy austenitic steel forgings. In general, only straight-beam inspecting using a back-reflection reference standard is used. However, utilization of Practice A 745/A 745M for austenitic steel forgings can be considered if flat-bottom hole reference standards or angle-beam examination of these grades are required.

10.3 Acceptance quality levels shall be established between purchaser and manufacturer on the basis of one or more of the following criteria.

10.3.1 *Straight-Beam Examination:*

10.3.1.1 No indications larger than some percentage of the reference back reflection.

10.3.1.2 No indications equal to or larger than the indication received from the flat-bottom hole in a specific reference block or blocks.

10.3.1.3 No areas showing loss of back reflection larger than some percentage of the reference back reflection.

10.3.1.4 No indications per 10.3.1.1 or 10.3.1.2 coupled with some loss of resultant back reflection per 10.3.1.3.

10.3.1.5 No indications exceeding the reference level specified in the DGS method.

10.3.2 *Angle-Beam Examination* — No indications exceeding a stated percentage of the reflection from a reference notch or of the amplitude reference line.

10.4 Intelligent application of ultrasonic quality levels involves an understanding of the effects of many parameters on examination results.

11. Keywords

11.1 angle beam examination; back-reflection; DGS; reference-block; straight beam examination; ultrasonic

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details shall be agreed upon by the manufacturer and the purchaser.

S1. REPORTING CRITERIA

S1.1 Reference block calibration shall be performed using at least three holes, spaced to approximate minimum, mean, and maximum thickness as tested, and shall be used to generate a distance amplitude correction (DAC) curve. The following hole sizes apply:

(a) $\frac{1}{16}$ in. [1.5 mm] flat bottom holes (FBH) for thicknesses less than 1.5 in. [40 mm]

(b) $\frac{1}{8}$ in. [3 mm] FBH for thicknesses of 1.5–6 in. [40–150 mm] inclusive

(c) $\frac{1}{4}$ in. [6 mm] FBH for thicknesses over 6 in. [150 mm]

S1.2 Reporting criteria include:

(a) all indications exceeding the DAC curve

(b) two or more indications separated by $\frac{1}{2}$ in. [12 mm] or less

APPENDIXES

(Nonmandatory Information)

X1. TYPICAL TUNING LEVEL COMPENSATION FOR THE EFFECTS OF FORGING CURVATURE

X1.1 The curve (Fig. X1.1) was determined for the following test conditions:

Material	Nickel-molybdenum-vanadium alloy steel (Specification A 469, Class 4)
Instrument	Type UR Reflectoscope
Search unit	$1^1/_8$ in. [30 mm] diameter quartz
Frequency	$2^1/_4$ MHz
Reference block	ASTM No. 3-0600 (aluminum)
Reflection area of reference curve	0.010 in.^{2} [6.5 mm^2] in nickel-molybdenum-vanadium alloy steel
Surface finish	250 μin. [6 μm] max. roughness

X1.2 To utilize curve, adjust reflectoscope sensitivity to obtain indicated ultrasonic response on ASTM No. 3-0600 reference block for each diameter as shown. A response of 1 in. [25 mm] sweep-to-peak is used for flat surfaces. Use attenuator to obtain desired amplitude, but do testing at 1 to 1 setting.

X2. INDICATION AMPLITUDE COMPENSATION FOR TEST DISTANCE VARIATIONS

X2.1 The curve (Fig. X2.1) has been determined for the following test conditions:

Material	Nickel-molybdenum-vanadium alloy steel (Specification A 469, Class 4)
Instrument	Type UR Reflectoscope
Search unit	$1^1/_8$ in. [30 mm] diameter quartz
Frequency	$2^1/_4$ MHz
Couplant	No. 20 oil
Reference block	ASTM No. 3-0600 (aluminum)
Reflection area of reference curve	0.010 in.^{2} [6.5 mm^2] in nickel-molybdenum-vanadium alloy steel
Surface finish	250 μin. max. roughness

X2.2 To utilize curve, establish amplitude from ASTM reference block to coincide with values from Appendix X1.

X3. BACKGROUND INFORMATION ON THE DGS METHODS

X3.1 The DGS method was developed to determine flaw sizes by comparison to a backwall echo produced on the part to be ultrasonic tested. The derivation of DGS curves is extensively covered and can be found in standard texts on ultrasonic testing, and will not be covered here. The distance or thickness of the forging (*A*) to be tested, as noted on the overlay, must be accurately defined on the CRT screen. The back reflection (*B*) of the part must be established and suitable gain added. Flaw echo indications that appear can be sized via the flaw size curves (*C*) on the overlay. Item (*D*) depicts the transducers that the overlay works in conjunction with and (*E*) depicts the series of curves that the overlay scales are matched to.

X4. COMPENSATION FOR CENTER HOLE ATTENUATION ON CYLINDRICAL BORED OR HOLLOW FORGINGS UTILIZING THE DGS METHOD

X4.1 The hole in a cylindrical bored forging causes sound scatter. In these cases, a correction is required which depends on the wall thickness and bore diameter.

X4.1.1 Determine the correction value in dB from the Nomogram (Fig. X4.1).

X4.1.2 Proceed as described in 7.2.2.3.

X4.1.3 With the GAIN-dB control, reduce the flaw detector gain by the correction value determined as per the Nomogram (Fig. X4.2). Thus, the flaw detector gain is accurately adjusted.

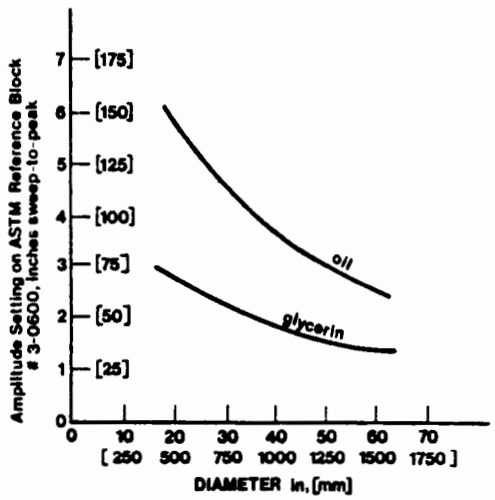


FIG. X1.1 TYPICAL COMPENSATION CURVE FOR EFFECTS OF FORGING CURVATURE

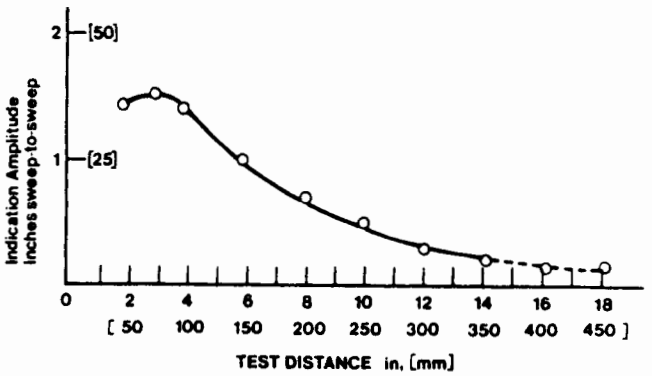


FIG. X2.1 TYPICAL DISTANCE–AMPLITUDE CORRECTION CURVE

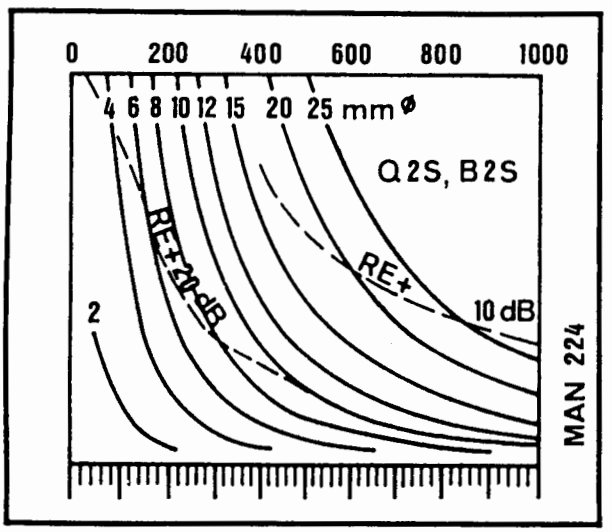
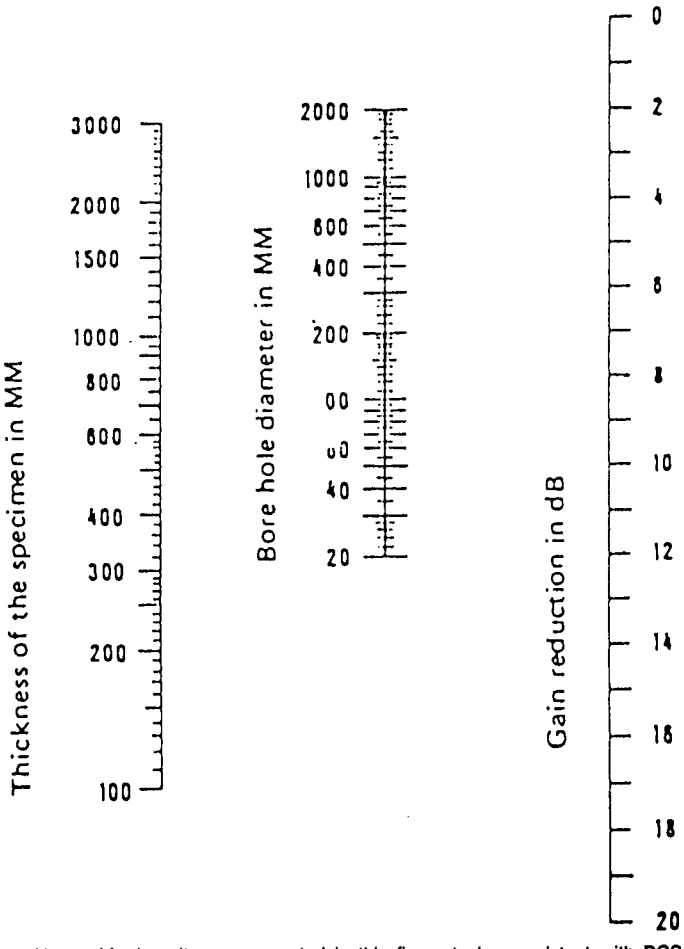


FIG. X4.1 EXAMPLE OF DGS OVERLAY



NOTE—Metric units are presented in this figure to be consistent with DGS scales presently available. Conversion to English units would also be acceptable.

FIG. X4.2 THE INFLUENCE OF A CENTRAL BORE ON THE BACKWALL ECHO AMPLITUDE OF CYLINDRICAL OR PLANE PARALLEL FORGINGS

STANDARD SPECIFICATION FOR STRAIGHT-BEAM ULTRASONIC EXAMINATION OF STEEL PLATES

SA-435/SA-435M

[Identical with ASTM Specification A 435/A 435M-90 (R1996)]

1. Scope

1.1 This specification covers the procedure and acceptance standards for straight-beam, pulse-echo, ultrasonic examination of rolled fully killed carbon and alloy steel plates, $\frac{1}{2}$ in. [12.5 mm] and over in thickness. It was developed to assure delivery of steel plates free of gross internal discontinuities such as pipe, ruptures, or laminations, and is to be used whenever the inquiry, contract, order, or specification states that the plates are to be subjected to ultrasonic examination.

1.2 Individuals performing examinations in accordance with this specification shall be qualified and certified in accordance with the requirements of the latest edition of ASNT SNT-TC-1A or an equivalent accepted standard. An equivalent standard is one which covers the qualification and certification of ultrasonic nondestructive examination candidates and which is acceptable to the purchaser.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents, therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Document

2.1 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

3. Apparatus

3.1 The manufacturer shall furnish suitable ultrasonic equipment and qualified personnel necessary for performing the test. The equipment shall be of the pulse-echo straight-beam type. The transducer is normally 1 to $1\frac{1}{8}$ in. [25 to 30 mm] in diameter or 1 in [25 mm] square; however, any transducer having a minimum active area of 0.7 in.^{2} [450 mm^2] may be used. The test shall be performed by one of the following methods: direct contact, immersion, or liquid column coupling.

3.2 Other search units may be used for evaluating and pinpointing indications.

4. Test Conditions

4.1 Conduct the examination in an area free of operations that interfere with proper functioning of the equipment.

4.2 Clean and smooth the plate surface sufficiently to maintain a reference back reflection from the opposite side of the plate at least 50% of the full scale during scanning.

4.3 The surface of plates inspected by this method may be expected to contain a residue of oil or rust or both. Any specified identification which is removed when grinding to achieve proper surface smoothness shall be restored.

5. Procedure

5.1 Ultrasonic examination shall be made on either major surface of the plate. Acceptance of defects in close proximity may require inspection from the second major

surface. Plates ordered in the quenched and tempered condition shall be tested following heat treatment.

5.2 A nominal test frequency of $2\frac{1}{4}$ MHz is recommended. Thickness, grain size, or microstructure of the material and nature of the equipment or method may require a higher or lower test frequency. However, frequencies less than 1 MHz may be used only on agreement with the purchaser. A clear, easily interpreted trace pattern should be produced during the examination.

5.3 Conduct the examination with a test frequency and instrument adjustment that will produce a minimum 50 to a maximum 75% of full scale reference back reflection from the opposite side of a sound area of the plate. While calibrating the instrument, sweep the crystal along the plate surface for a distance of at least $1T$ or 6 in. [150 mm], whichever is the greater, and note the position of the back reflection. A shift in location of the back reflection during calibration shall be cause for recalibration of the instrument.

5.4 Scanning shall be continuous along perpendicular grid lines on nominal 9-in. [225-mm] centers, or at the manufacturer's option, shall be continuous along parallel paths, transverse to the major plate axis, on nominal 4-in. [100-mm] centers, or shall be continuous along parallel paths parallel to the major plate axis, on 3-in [75-mm] or smaller centers. A suitable couplant such as water, soluble oil, or glycerin, shall be used.

5.5 Scanning lines shall be measured from the center or one corner of the plate. An additional path shall be scanned within 2 in. [50 mm] of all edges of the plate on the scanning surface.

5.6 Where grid scanning is performed and complete loss of back reflection accompanied by continuous indications is detected along a given grid line, the entire surface area of the squares adjacent to this indication shall be scanned continuously. Where parallel path scanning is performed and complete loss of back reflection accompanied by continuous indications is detected, the entire surface area of a 9 by 9-in. [225 by 225-mm] square centered on this indication shall be scanned continuously. The true boundaries where this condition exists shall be established in either method by the following technique: Move the transducer away from the center of the discontinuity until the heights of the back reflection and discontinuity indications are equal. Mark the plate at a point equivalent to the center of the transducer. Repeat the operation to establish the boundary.

6. Acceptance Standards

6.1 Any discontinuity indication causing a total loss of back reflection which cannot be contained within a circle, the diameter of which is 3 in. [75 mm] or one half of the plate thickness, whichever is greater, is unacceptable.

6.2 The manufacturer reserves the right to discuss rejectable ultrasonically tested plates with the purchaser with the object of possible repair of the ultrasonically indicated defect before rejection of the plate.

6.3 The purchaser's representative may witness the test.

7. Marking

7.1 Plates accepted in accordance with this specification shall be identified by stamping or stenciling UT 435 adjacent to marking required by the material specification.

SUPPLEMENTARY REQUIREMENTS

The following shall apply only if specified in the order:

S1.

Instead of the scanning procedure specified by 5.4 and 5.5, and as agreed upon between manufacturer and purchaser, 100% of one major plate surface shall be scanned. Scanning shall be continuous along parallel paths, transverse or parallel to the major plate axis, with not less than 10% overlap between each path.

STANDARD SPECIFICATION FOR ULTRASONIC ANGLE-BEAM EXAMINATION OF STEEL PLATES

SA-577/SA-577M

[Identical with ASTM Specification A 577/A 577M-90 (R1996)]

1. Scope

1.1 This specification covers an ultrasonic angle-beam procedure and acceptance standards for the detection of internal discontinuities not laminar in nature and of surface imperfections in a steel plate. This specification is intended for use only as a supplement to specifications which provide straight-beam ultrasonic examination.

NOTE — An internal discontinuity that is laminar in nature is one whose principal plane is parallel to the principal plane of the plate.

1.2 Individuals performing examinations in accordance with this specification shall be qualified and certified in accordance with the requirements of the latest edition of ASNT SNT-TC-1A or an equivalent accepted standard. An equivalent standard is one which covers the qualification and certification of ultrasonic nondestructive examination candidates and which is acceptable to the purchaser.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Document

2.1 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

3. Ordering Information

3.1 The inquiry and order shall indicate any additions to the provisions of this specification as prescribed in 14.1.

4. Examination Conditions

4.1 The examination shall be conducted in an area free of operations that interfere with proper performance of the examination.

4.2 The surface of the plate shall be conditioned as necessary to provide a clear, easily interpreted trace pattern on the screen. Any specified identification which is removed to achieve proper surface smoothness shall be restored.

5. Apparatus

5.1 The amplitude linearity shall be checked by positioning the transducer over the depth resolution notch in the IIW or similar block so that the signal from the notch is approximately 30% of the screen height, and the signal from one of the back surfaces is approximately 60% of the screen height (two times the height of the signal from the notch). A curve is then plotted showing the deviations from the above established 2:1 ratio that occurs as the amplitude of the signal from the notch is raised in increments of one scale division until the back reflection signal reaches full scale, and then is lowered in increments of one scale division until the notch signal reaches one scale division. At each increment the ratio of the two signals is determined. The ratios are plotted on the graph at the position corresponding to the larger signal. Between the limits of 20% and 80% of the screen height the ratio shall be within 10% of 2:1. Instrument settings used during inspection shall not cause variation outside the 10% limits established above.

5.2 The search unit shall be a 45-deg (in steel) angle-beam type with active transducer length and width dimensions of a minimum of $\frac{1}{2}$ in. [12.5 mm] and a maximum of 1 in. [25 mm]. Search units of other sizes and angles may be used for additional exploration and evaluation.

6. Examination Frequency

6.1 The ultrasonic frequency selected for the examination shall be the highest frequency that permits detection of the required calibration notch, such that the amplitude of the indication yields a signal-to-noise ratio of at least 3:1.

7. Calibration Reflector

7.1 A calibration notch, the geometry of which has been agreed upon by the purchaser and the manufacturer, with a depth of 3% of the plate thickness, shall be used to calibrate the ultrasonic examination. The notch shall be at least 1 in. [25 mm] long.

7.2 Insert the notch or notches on the surface of the plate so that they are perpendicular to the long axis at a distance of 2 in. [50 mm] or more from the short edge of the plate. Locate the notch not less than 2 in. [50 mm] from the long edges of the plate.

7.3 When the notch cannot be inserted in the plate to be tested, it may be placed in a calibration plate of ultrasonically similar material. The calibration plate will be considered ultrasonically similar if the height of the first back reflection through it is within 25% of that through the plate to be tested at the same instrument calibration. The calibration plate thickness shall be within 1 in. [25 mm] of the thickness of plates to be tested, for plates of 2 in. [50 mm] thickness and greater and within 10% of plates whose thickness is less than 2 in. [50 mm].

7.4 For plate thicknesses greater than 2 in. [50 mm], insert a second calibration notch as described in 7.2, on the opposite side of the plate.

8. Calibration Procedure

8.1 *Plate 2 in.* [50 mm] *and Under in Thickness:*

8.1.1 Place the search unit on the notched surface of the plate with the sound beam directed at the broad side of the notch and position to obtain maximum amplitude from the first vee-path indication which is clearly resolved from the initial pulse. Adjust the instrument gain so that this reflection amplitude is at least 50 but not more than 75% of full screen height. Record the location and amplitude of this indication on the screen.

8.1.2 Move the search unit away from the notch until the second vee-path indication is obtained. Position the search unit for maximum amplitude and record the indication amplitude. Draw a line between the peaks from the two successive notch indications on the screen. This line is the distance amplitude curve (DAC) for this material and shall be a 100% reference line for reporting indication amplitudes.

8.2 *Plate Over 2 to 6 in.* [50 to 150 mm] *Inclusive in Thickness:*

8.2.1 Place the search unit on the test surface aimed at the broad side of the notch on the opposite surface of the plate. Position the search unit to obtain a maximum one-half vee-path indication amplitude. Adjust the instrument gain so that this amplitude is at least 50% but not more than 80% of full screen height. Record the location and amplitude on the screen. Without adjusting the instrument settings, repeat this procedure for the $1\frac{1}{2}$ vee-path indication.

8.2.2 Without adjusting the instrument settings, reposition the search unit to obtain a maximum full vee-path indication from the notch on the test surface. Record the location and amplitude on the screen.

8.2.3 Draw a line on the screen connecting the points established in 8.2.1 and 8.2.2. This curve shall be a DAC for reporting indication amplitudes.

8.3 *Plate Over 6 in.* [150 mm] *in Thickness:*

8.3.1 Place the search unit on the test surface aimed at the broad side of the notch on the opposite surface of the plate. Position the search unit to obtain a maximum one-half vee-path indication amplitude. Adjust the instrument gain so that this amplitude is at least 50% but not more than 80% of full screen height. Record the location and amplitude on the screen.

8.3.2 Without adjusting the instrument settings, reposition the search unit to obtain a maximum full vee-path indication from the notch on the test surface. Record the location and amplitude on the screen.

8.3.3 Draw a line on the screen connecting the points established in 8.3.1 and 8.3.2. This line shall be a DAC for reporting indication amplitudes.

9. Examination Procedure

9.1 Scan one major surface of the plate on grid lines perpendicular and parallel to the major rolling direction. Grid lines shall be on 9-in. [225-mm] centers. Use a suitable couplant such as water, oil, or glycerin. Scan by placing the search unit near one edge with the ultrasonic beam directed toward the same edge and move the search unit along the grid line in a direction perpendicular to the edge to a location two plate thicknesses beyond the plate center. Repeat this scanning procedure on all grid lines from each of the four edges.

9.2 Measure grid lines from the center or one corner of the plate.

9.3 Position the search unit to obtain a maximum indication amplitude from each observed discontinuity.

9.4 For each discontinuity indication that equals or exceeds the DAC, record the location and length, and the amplitude to the nearest 25%. No indication with an amplitude less than the DAC shall be recorded.

9.5 At each recorded discontinuity location, conduct a 100% examination of the mass under a 9-in. [225-mm] square which has the recorded discontinuity position at its center. Conduct the examination in directions perpendicular and parallel to the major rolling direction.

10. Acceptance Standard

10.1 Any discontinuity indication that equals or exceeds the DAC shall be considered unacceptable unless additional exploration by the longitudinal method indicates it is laminar in nature.

11. Rehearing

11.1 The manufacturer reserves the right to discuss unacceptable ultrasonically examined plate with the purchaser with the object of possible repair of the ultrasonically indicated discontinuity before rejection of the plate.

12. Inspection

12.1 The purchaser's representative shall have access, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the ultrasonic examination of the material ordered. The manufacturer shall afford the representative all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All examinations and verifications shall be so conducted as not to interfere unnecessarily with the manufacturer's operations.

13. Marking

13.1 Plates accepted in accordance with this specification shall be identified by metal stamping or stencilling "UT A 577" in one corner of the plate, at a location within 6 in. [150 mm] of the heat number.

14. Report

14.1 Unless otherwise agreed upon between the purchaser and manufacturer, the manufacturer shall report the following data:

14.1.1 Plate identity including pin-pointed recordable indication locations, lengths, and amplitudes.

14.1.2 Examination parameters, including: couplant; search unit type, angle, frequency, and size; instrument make, model, and serial number; and calibration plate description.

14.1.3 Date of examination and name of operator.

STANDARD SPECIFICATION FOR STRAIGHT-BEAM ULTRASONIC EXAMINATION OF PLAIN AND CLAD STEEL PLATES FOR SPECIAL APPLICATIONS

SA-578/SA-578M

(Identical with ASTM Specification A 578/A 578M-96)

1. Scope

1.1 This specification covers the procedure and acceptance standards for straight-beam, pulse-echo, ultrasonic examination of rolled carbon and alloy plain and clad steel plates, $^{3}/_{8}$ in. [10 mm] in thickness and over, for special applications. The method will detect internal discontinuities parallel to the rolled surfaces. Three levels of acceptance standards are provided. Supplementary requirements are provided for examination of clad plate and for alternative procedures.

1.2 Individuals performing examinations in accordance with this specification shall be qualified and certified in accordance with the requirements of the latest edition of ASNT SNT-TC-1A or an equivalent accepted standard. An equivalent standard is one which covers the qualification and certification of ultrasonic nondestructive examination candidates and which is acceptable to the purchaser.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 263 Specification for Corrosion-Resisting Chromium Steel–Clad Plate, Sheet, and Strip

A 264 Specification for Stainless Chromium-Nickel Steel–Clad Plate, Sheet, and Strip

A 265 Specification for Nickel and Nickel-Base Alloy–Clad Steel Plate

2.2 *ANSI Standard:*

B 46.1 Surface Texture

2.3 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

3. Ordering Information

3.1 The inquiry and order shall indicate the following:

3.1.1 Acceptance level requirements (Sections 7, 8, and 9). Acceptance Level B shall apply unless otherwise agreed to by purchaser and manufacturer.

3.1.2 Any additions to the provisions of this specification as prescribed in 5.2, 12.1, and Section 13.

3.1.3 Supplementary requirements, if any.

4. Apparatus

4.1 The amplitude linearity shall be checked by positioning the transducer over the depth resolution notch in the IIW or similar block so that the signal from the notch is approximately 30% of the screen height, and the signal from one of the back surfaces is approximately 60% of the screen height (two times the height of the signal from the notch). A curve is then plotted showing the deviations

from the above established 2:1 ratio that occurs as the amplitude of the signal from the notch is raised in increments of one scale division until the back reflection signal reaches full scale, and then is lowered in increments of one scale division until the notch signal reaches one scale division. At each increment the ratio of the two signals is determined. The ratios are plotted on the graph at the position corresponding to the larger signal. Between the limits of 20% and 80% of the screen height, the ratio shall be within 10% of 2:1. Instrument settings used during inspection shall not cause variation outside the 10% limits established above.

4.2 The transducer shall be 1 or $1\frac{1}{8}$ in. [25 or 30 mm] in diameter or 1 in. [25 mm] square.

4.3 Other search units may be used for evaluating and pinpointing indications.

5. Procedure

5.1 Perform the inspection in an area free of operations that interfere with proper performance of the test.

5.2 Unless otherwise specified, make the ultrasonic examination on either major surface of the plate.

5.3 The plate surface shall be sufficiently clean and smooth to maintain a first reflection from the opposite side of the plate at least 50% of full scale during scanning. This may involve suitable means of scale removal at the manufacturer's option. Condition local rough surfaces by grinding. Restore any specified identification which is removed when grinding to achieve proper surface smoothness.

5.4 Perform the test by one of the following methods: direct contact, immersion, or liquid column coupling. Use a suitable couplant such as water, soluble oil, or glycerin. As a result of the test by this method, the surface of plates may be expected to have a residue of oil or rust, or both.

5.5 A nominal test frequency of $2\frac{1}{4}$ MHz is recommended. When testing plates less than $\frac{3}{4}$ in. [20 mm] thick, a frequency of 5 MHz may be necessary. Thickness, grain size or microstructure of the material and nature of the equipment or method may require a higher or lower test frequency. Use the transducers at their rated frequency. A clean, easily interpreted trace pattern should be produced during the examination.

5.6 *Scanning:*

5.6.1 Scanning shall be along continuous perpendicular grid lines on nominal 9-in. [225-mm] centers, or at the option of the manufacturer, shall be along continuous parallel paths, transverse to the major plate axis, on nominal 4-in. [100-mm] centers, or shall be along continuous parallel paths parallel to the major plate axis, on 3-in. [75-mm] or smaller centers. Measure the lines from the center or one corner of the plate with an additional path within 2 in. [50 mm] of all edges of the plate on the searching surface.

5.6.2 Conduct the general scanning with an instrument adjustment that will produce a first reflection from the opposite side of a sound area of the plate from 50% to 90% of full scale. Minor sensitivity adjustments may be made to accommodate for surface roughness.

5.6.3 When a discontinuity condition is observed during general scanning, adjust the instrument to produce a first reflection from the opposite side of a sound area of the plate of 75 ± 5% of full scale. Maintain this instrument setting during evaluation of the discontinuity condition.

6. Recording

6.1 Record all discontinuities causing complete loss of back reflection.

6.2 For plates $\frac{3}{4}$ in. [20 mm] thick and over, record all indications with amplitudes equal to or greater than 50% of the initial back reflection and accompanied by a 50% loss of back reflection.

NOTE 2 — Indications occurring midway between the initial pulse and the first back reflection may cause a second reflection at the location of the first back reflection. When this condition is observed it shall be investigated additionally by use of multiple back reflections.

6.3 Where grid scanning is performed and recordable conditions as in 6.1 and 6.2 are detected along a given grid line, the entire surface area of the squares adjacent to this indication shall be scanned. Where parallel path scanning is performed and recordable conditions as in 6.1 and 6.2 are detected, the entire surface area of a 9 by 9-in. [225 by 225-mm] square centered on this indication shall be scanned. The true boundaries where these conditions exist shall be established in either method by the following technique: Move the transducer away from the center of the discontinuity until the height of the back reflection and discontinuity indications are equal. Mark the plate at a point equivalent to the center of the transducer. Repeat the operation to establish the boundary.

7. Acceptance Standard — Level A

7.1 Any area where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. [75 mm] or $\frac{1}{2}$ of the plate thickness, whichever is greater, is unacceptable.

8. Acceptance Standards — Level B

8.1 Any area where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a circle whose diameter is 3 in. [75 mm] or ½ of the plate thickness, whichever is greater, is unacceptable.

8.2 In addition, two or more discontinuities smaller than described in 8.1 shall be unacceptable unless separated by a minimum distance equal to the greatest diameter of the larger discontinuity or unless they may be collectively encompassed by the circle described in 8.1.

9. Acceptance Standard — Level C

9.1 Any area where one or more discontinuities produce a continuous total loss of back reflection accompanied by continuous indications on the same plane that cannot be encompassed within a 1-in. [25-mm] diameter circle is unacceptable.

10. Rehearing

10.1 The manufacturer reserves the right to discuss rejectable ultrasonically tested plate with the purchaser with the object of possible repair of the ultrasonically indicated defect before rejection of the plate.

11. Inspection

11.1 The inspector representing the purchaser shall have access at all times, while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the ultrasonic testing of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspections shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be conducted without interfering unnecessarily with the manufacturer's operations.

12. Marking

12.1 Plates accepted according to this specification shall be identified by stenciling (stamping) "UT A 578 — A" on one corner for Level A, "UT A 578 — B" for Level B, and "UT A 578 — C" for Level C. The supplement number shall be added for each supplementary requirement ordered.

13. Report

13.1 Unless otherwise agreed to by the purchaser and the manufacturer, the manufacturer shall report the following data:

13.1.1 All recordable indications listed in Section 6 on a sketch of the plate with sufficient data to relate the geometry and identity of the sketch to those of the plate.

13.1.2 Test parameters including: Make and model of instrument, test frequency, surface condition, transducer (type and frequency), and couplant.

13.1.3 Date of test.

14. Keywords

14.1 nondestructive testing; pressure containing parts; pressure vessel steels; steel plate for pressure vessel applications; steel plates; ultrasonic examinations

SUPPLEMENTARY REQUIREMENTS

These supplementary requirements shall apply only when individually specified by the purchaser. When details of these requirements are not covered herein, they are subject to agreement between the manufacturer and the purchaser.

S1. Scanning

S1.1 Scanning shall be continuous over 100% of the plate surface.

S2. Acceptance Standard

S2.1 Any recordable condition listed in Section 6 that (1) is continuous, (2) is on the same plane (within 5% of the plate thickness), and (3) cannot be encompassed by a 3-in. [75-mm] diameter circle, is unacceptable. Two or more recordable conditions (see Section 5), that (1) are on the same plane (within 5% of plate thickness), (2) individually can be encompassed by a 3-in. [75-mm] diameter circle, (3) are separated from each other by a distance less than the greatest dimension of the smaller indication, and (4) collectively cannot be encompassed by a 3-in. [75-mm] diameter circle, are unacceptable.

S2.2 An acceptance level more restrictive than Section 7 or 8 shall be used by agreement between the manufacturer and purchaser.

S3. Procedure

S3.1 The manufacturer shall provide a written procedure in accordance with this specification.

S4. Certification

S4.1 The manufacturer shall provide a written certification of the ultrasonic test operator's qualifications.

S5. Surface Finish

S5.1 The surface finish of the plate shall be conditioned to a maximum 125 μin. [3 μm] AA (see ANSI B46.1) prior to test.

S6. Examination of Integrally Bonded Clad Plate, Acceptance Level S6

S6.1 Examine the plate from the clad surface using procedures and techniques in accordance with this specification.

S6.2 Inspect the backing steel to Level B, or, if specifically requested by customer, to Level A or Level C.

S6.3 The cladding shall be interpreted to be unbonded when there is complete loss of back reflection accompanied by an echo indication from the plane of the interface of the clad and backing steel.

S6.4 Unless otherwise specified, indications of unbond determined in accordance with S6.3 that cannot be encompassed within a 3-in. [75-mm] diameter circle shall be weld repaired subject to the requirements and limitations for the repair of defects in cladding of the appropriate material specification.

S6.5 This supplementary requirement is applicable to Specifications A 263, A 264, and A 265.

S7. Examination of Integrally Bonded Clad Plate, Acceptance Level S7

S7.1 The plate shall be examined from the clad surface using procedures and techniques according to this specification except 100% surface search is mandatory.

S7.2 Inspect the backing steel to Level B, or, if specifically requested by customer, to Level A or Level C.

S7.3 The cladding shall be interpreted to be unbonded when there is complete loss of back reflection accompanied by an echo indication from the plane of the interface of the clad and backing steel.

S7.4 Unless otherwise specified, indications of unbond determined in accordance with S7.3 that cannot be encompassed within a 1-in. [25-mm] diameter circle shall be weld repaired subject to the requirements and limitations for the repair of defects in cladding of the appropriate material specification. Additionally, prior approval must be obtained if the weld repaired surface exceeds 1.5% of the cladding surface.

S7.5 This supplementary requirement is applicable to Specifications A 263, A 264, and A 265.

S8. Ultrasonic Examination Using Flat Bottom Hole Calibration (for Plates 4 in. [100 mm] Thick and Greater)

S8.1 Use the following calibration and recording procedures in place of 5.6.2, 5.6.3, and Section 6.

S8.2 The transducer shall be in accordance with 4.2.

TABLE S8.1
CALIBRATION HOLE DIAMETER AS A FUNCTION OF PLATE THICKNESS (S8)

Plate Thickness, in. [mm]	4–6 [100–150]	> 6–9 [> 150–225]	> 9–12 [> 225–300]	> 12–20 [> 300–500]
Hole Diameter, in. [mm]	5/8 [16]	3/4 [19]	7/8 [22]	1 1/8 [29]

S8.3 *Reference Reflectors* — The *T*/4, *T*/2, and 3*T*/4 deep flat bottom holes shall be used to calibrate the equipment. The flat bottom hole diameter shall be in accordance with Table S8.1. The holes may be drilled in the plate to be examined if they can be located without interfering with the use of the plate, in a prolongation of the plate to be examined, or in a reference block of the same nominal composition, and thermal treatment as the plate to be examined. The surface of the reference block shall be no better to the unaided eye than the plate surface to be examined. The reference block shall be of the same nominal thickness (within 75 to 125% or 1 in. [25 mm] of the examined plate, whichever is less) and shall have acoustical properties similar to the examined plate. Acoustical similarity is presumed when, without a change in instrument setting, comparison of the back reflection signals between the reference block and the examined plate shows a variation of 25% or less.

S8.4 *Calibration Procedure:*

S8.4.1 Couple and position the search unit for maximum amplitudes from the reflectors at *T*/4, *T*/2, and 3*T*/4. Set the instrument to produce a 75 ± 5% of full scale indication from the reflector giving the highest amplitude.

S8.4.2 Without changing the instrument setting, couple and position the search unit over each of the holes and mark on the screen the maximum amplitude from each hole and each minimum remaining back reflection.

S8.4.3 Mark on the screen half the vertical distance from the sweep line to each maximum amplitude hole mark. Connect the maximum amplitude hole marks and extend the line through the thickness for the 100% DAC (distance–amplitude correction curve). Similarly connect and extend the half maximum amplitude marks for the 50% DAC.

S8.5 *Recording:*

S8.5.1 Record all areas where the remaining back reflection is smaller than the highest of the minimum remaining back reflections found in S8.4.2.

S8.5.2 Record all areas where indications exceed 50% DAC.

S8.5.3 Where recordable conditions listed in S8.5.1 and S8.5.2 are detected along a given grid line, continuously scan the entire surface area of the squares adjacent to the condition and record the boundaries or extent of each recordable condition.

S8.6 Scanning shall be in accordance with 5.6.

S8.7 The acceptance levels of Section 7 or 8 shall apply as specified by the purchaser except that the recordable condition shall be as given in S8.5.

S9. Ultrasonic Examination of Electroslag Remelted (ESR) and Vacuum-Arc Remelted (VAR) Plates, from 1 to 16 in. [25 to 400 mm] in Thickness, Using Flat-Bottom Hole Calibration and Distance–Amplitude Corrections

S9.1 The material to be examined must have a surface finish of 200 μin. [5 μm] as maximum for plates up to 8 in. [200 mm] thick, inclusive, and 250 μin. [6 μm] as maximum for plates over 8 to 16 in. [200 to 400 mm] thick.

S9.2 Use the following procedures in place of 5.6.1, 5.6.2, 5.6.3, and Section 6.

S9.3 The transducer shall be in accordance with 4.2.

S9.4 *Reference Reflectors* — The *T*/4, *T*/2, and 3*T*/4 deep flat bottom holes shall be used to calibrate the equipment. The flat bottom hole diameter shall be in accordance with Table S9.1. The flat bottoms of the holes shall be within 1° of parallel to the examination surface. The holes may be drilled in the plate to be examined if they can be located without interfering with the use of the plate, in a prolongation of the plate to be examined, or in a reference block of the same nominal composition and thermal treatment as the plate to be examined. The surface of the reference block shall be no better to the unaided eye than the plate surface to be examined. The reference block shall be of the same nominal thickness (within 75 to 125% or 1 in. [25 mm] of the examined plate, whichever is less) and shall have acoustical properties similar to the examined plate. Acoustical similarity is presumed when, without a change in instrument setting, comparison of the back reflection signals between the reference block and the examined plate shows a variation of 25% or less.

S9.5 *Calibration Procedure:*

S9.5.1 Couple and position the search unit for maximum amplitudes from the reflectors at *T*/4, *T*/2, and 3*T*/

TABLE S9.1
CALIBRATION HOLE DIAMETER AS A FUNCTION OF PLATE THICKNESS (S9)

Plate Thickness, in. [mm]	1–4 [25–100]	> 4–8 [> 100–200]	> 8–12 [> 200–300]	> 12–16 [> 300–400]
Hole Diameter, in. [mm]	1/8 [3]	1/4 [6]	3/8 [10]	1/2 [13]

4. Set the instrument to produce a 75 ± 5% of full-scale indication from the reflector giving the highest amplitude.

S9.5.2 Without changing the instrument setting, couple and position the search unit over each of the holes and mark on the screen the maximum amplitude from each of the holes.

S9.5.3 Mark on the screen half the vertical distances from the sweep line to each maximum amplitude hole mark. Connect the maximum amplitude hole marks and extend the line through the thickness for the 100% DAC (distance–amplitude correction curve). Similarly connect and extend the half maximum amplitude marks for the 50% DAC.

S9.6 *Scanning* — Scanning shall cover 100% of one major plate surface, with the search unit being indexed between each pass such that there is at least 15% overlap of adjoining passes in order to assure adequate coverage for locating discontinuities.

S9.7 *Recording* — Record all areas where the back reflection drops below the 50% DAC. If the drop in back reflection is not accompanied by other indications on the screen, recondition the surface in the area and reexamine ultrasonically. If the back reflection is still below 50% DAC, the loss may be due to the metallurgical structure of the material being examined. The material shall be held for metallurgical review by the purchaser and manufacturer.

S9.8 *Acceptance Standards* — Any indication that exceeds the 100% DAC shall be considered unacceptable. The manufacturer may reserve the right to discuss rejectable ultrasonically examined material with the purchaser, the object being the possible repair of the ultrasonically indicated defect before rejection of the plate.

STANDARD PRACTICE FOR CASTINGS, CARBON, LOW-ALLOY, AND MARTENSITIC STAINLESS STEEL, ULTRASONIC EXAMINATION THEREOF

SA-609/SA-609M

[Identical with ASTM Specification A 609/A 609M-91 (R1997)]

1. Scope

1.1 This practice covers the standards and procedures for the pulse-echo ultrasonic examination of heat-treated carbon, low-alloy, and martensitic stainless steel castings by the longitudinal-beam technique.

1.2 This practice is to be used whenever the inquiry, contract, order, or specification states that castings are to be subjected to ultrasonic examination in accordance with Practice A 609/A 609M.

1.3 This practice contains two procedures for ultrasonic inspection of carbon, low-alloy, and martensitic stainless steel castings, that is, Procedure A and Procedure B. Procedure A is the original A 609/A 609M practice and requires calibration using a series of test blocks containing flat bottomed holes. It also provides supplementary requirements for angle beam testing. Procedure B requires calibration using a back wall reflection from a series of solid calibration blocks.

NOTE 1 — Ultrasonic examination and radiography are not directly comparable. This examination technique is intended to complement Guide E 94 in the detection of discontinuities.

1.4 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with this practice.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 217/A 217M Specification for Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service

E 94 Guide for Radiographic Testing

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments

2.2 *Other Document:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

3. Ordering Information

3.1 The inquiry and order should specify which procedure is to be used. If a procedure is not specified, Procedure A shall be used.

3.2 *Procedure A — Flat-Bottomed Hole Calibration Procedure:*

3.2.1 When this practice is to be applied to an inquiry, contract, or order, the purchaser shall furnish the following information:

3.2.1.1 Quality levels for the entire casting or portions thereof,

3.2.1.2 Sections of castings requiring longitudinal-beam examination,

3.2.1.3 Sections of castings requiring dual element examination,

3.2.1.4 Sections of castings requiring supplementary examination, using the angle-beam procedure

described in Supplementary Requirement S1 in order to achieve more complete examination, and

3.2.1.5 Any requirements additional to the provisions of this practice.

3.3 *Procedure B: Back-Wall Reflection Calibration Procedure* — When this procedure is to be applied to an inquiry, contract, or order, the purchaser shall designate the quality levels for the entire casting or applicable portions.

PROCEDURE A — FLAT-BOTTOMED HOLE CALIBRATION PROCEDURE

4. Apparatus

4.1 *Electronic Apparatus:*

4.1.1 An ultrasonic, pulsed, reflection type of instrument that is capable of generating, receiving, and amplifying frequencies of at least 1 to 5 MHz.

4.1.2 The ultrasonic instrument shall provide linear presentation (within ±5%) for at least 75% of the screen height (sweep line to top of screen). Linearity shall be determined in accordance with Practice E 317 or equivalent electronic means.

4.1.3 The electronic apparatus shall contain a signal attenuator or calibrated gain control that shall be accurate over its useful range to ±10% of the nominal attenuation or gain ratio to allow measurement of signals beyond the linear range of the instrument.

4.2 *Search Units:*

4.2.1 *Longitudinal Wave,* internally grounded, having a ½ to 1⅛ in. [13 to 28 mm] diameter or 1 in. [25 mm] square piezo-electric elements. Based on the signals-to-noise ratio of the response pattern of the casting, a frequency in the range from 1 to 5 MHz shall be used. The background noise shall not exceed 25% of the distance–amplitude correction curve (DAC). Transducers shall be utilized at their rated frequencies.

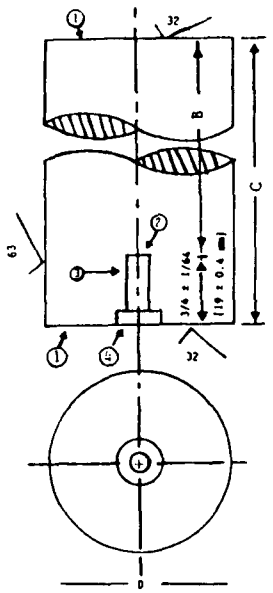
4.2.2 *Dual-Element,* 5 MHz, ½ by 1 in. [13 by 25 mm], 12° included angle search units are recommended for sections 1 in. [25 mm] and under.

4.2.3 Other frequencies and sizes of search units may be used for evaluating and pinpointing indications.

4.3 *Reference Blocks:*

4.3.1 Reference blocks containing flat-bottom holes shall be used to establish test sensitivity in accordance with 8.2.

4.3.2 Reference blocks shall be made from cast steels that give an acoustic response similar to the castings being examined.



NOTE 1—Opposite ends of reference block shall be flat and parallel within 0.001 in. [0.025 mm].
NOTE 2—Bottom of flat-bottom hole shall be flat within 0.002-in. [0.051 mm] and the finished diameter shall be ¼ + 0.002 in. [6.4 + 0.050 mm].
NOTE 3—Hole shall be straight and perpendicular to entry surface within 0°, 30 min and located within 1/32 in. [0.80 mm] of longitudinal axis.
NOTE 4—Counter bore shall be ½ in. [15.0 mm] diameter by ⅛ in. [5 mm] deep.

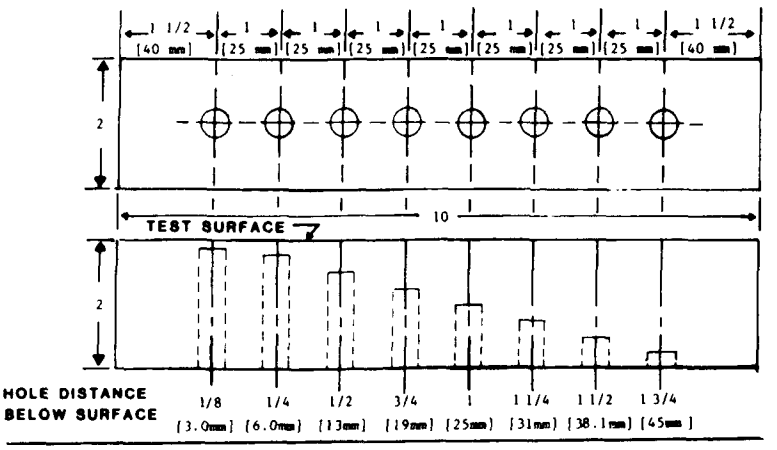
FIG. 1 ULTRASONIC STANDARD REFERENCE BLOCK

TABLE 1
DIMENSIONS AND IDENTIFICATION OF REFERENCE BLOCKS IN THE BASIC SET (SEE FIG. 1)

Hole Diameter in 1/64ths, in. [mm]	Metal Distance (*B*), in.[A] [mm]	Overall Length (*C*), in. [mm]	Width or Diameter (*D*), min, in. [mm]	Block Identification Number
16 [6.4]	1 [25]	1¾ [45]	2 [50]	16-0100
16 [6.4]	2 [50]	2¾ [70]	2 [50]	16-0200
16 [6.4]	3 [75]	3¾ [95]	2 [50]	16-0300
16 [6.4]	6 [150]	6¾ [170]	3 [75]	16-0600
16 [6.4]	10 [255]	10¾ [275]	4 [100]	16-1000
16 [6.4]	B	B + ¾ [B + 20]	5 [125]	16-B00[B]

[A] Tolerance ± 1/8 in. [3 mm].
[B] Additional supplemental blocks for testing thickness greater than 10 in. [250 mm], see 4.3.3.

4.3.3 The design of reference blocks shall be in accordance with Fig. 1, and the basic set shall consist of those blocks listed in Table 1. When section thicknesses over 15 in. [380 mm] are to be inspected, an additional block of the maximum test thickness shall be made to supplement the basic set.



NOTE 1—Entrant surface shall be 250 μin. [6.3 μm] or finer.
NOTE 2—The $^{3}/_{32}$-in. [2.4 mm] flat-bottom hole must be flat within 0.002 in. [0.05 mm]. Diameter must be within +0.005 in. [0.13 mm] of the required diameter. Hole axis must be perpendicular to the block and within an angle of 0°, 30 min.
NOTE 3—Hole shall be plugged following checking for ultrasonic response.

in.	[mm]	in.	[mm]
⅛	[3]	1¼	[32]
¼	[6]	1½	[38]
½	[13]	1¾	[44]
¾	[19.0]	2	[50]
1	[25]	10	[254]

FIG. 2 ULTRASONIC STANDARD REFERENCE BLOCK FOR DUAL-SEARCH UNIT CALIBRATION

4.3.4 Machined blocks with $^{3}/_{32}$-in. [2.4-mm] diameter flat-bottom holes at depths from the entry surface of $^{1}/_{8}$ in. [3 mm], $^{1}/_{2}$ in. [13 mm], or $^{1}/_{2}t$ and $^{3}/_{4}$ in. [19 mm], or $^{3}/_{4}t$ (where t = thickness of the block) shall be used to establish the DAC for the dual-element search units (see Fig. 2).

4.3.5 Each reference block shall be permanently identified along the side of the block indicating the material and the block identification.

4.4 *Couplant* — A suitable couplant having good wetting characteristics shall be used between the search unit and examination surface. The same couplant shall be used for calibrations and examinations.

5. Personnel Requirements

5.1 The manufacturer shall be responsible for assigning qualified personnel to perform ultrasonic examination in conformance with the requirements of this practice.

5.2 Personnel performing ultrasonic examinations in accordance with this practice shall be familiar with the following:

5.2.1 Ultrasonic terminology,

5.2.2 Instrument calibration,

5.2.3 Effect of transducer material, size, frequency, and mode on test results,

5.2.4 Effect of material structure (grain size, cleanliness, etc.) on test results,

5.2.5 Effect of test distance on test results,

5.2.6 Effect of nonlinearity on test results,

5.2.7 Effect of thickness and orientation of discontinuities on test results, and

5.2.8 Effect of surface roughness on test results.

5.3 A qualification record (see Note 2) of personnel considered suitable by the manufacturer to perform examinations in accordance with this practice shall be available upon request.

NOTE 2 — SNT-TC-1A, Ultrasonic Testing Method, provides a recommended procedure for qualifying personnel. Other personnel qualification requirement documents may be used when agreed upon between the purchaser and the supplier.

6. Casting Conditions

6.1 Castings shall receive at least an austenitizing heat treatment before being ultrasonically examined.

6.2 Test surfaces of castings shall be free of material that will interfere with the ultrasonic examination. They may be as cast, blasted, ground, or machined.

6.3 The ultrasonic examination shall be conducted prior to machining that prevents an effective examination of the casting.

7. Test Conditions

7.1 To assure complete coverage of the specified casting section, each pass of the search unit shall overlap by at least 10% of the width of the transducer.

7.2 The rate of scanning shall not exceed 6 in./s (150 mm/s).

7.3 The ultrasonic beam shall be introduced perpendicular to the examination surface.

8. Procedure

8.1 Adjust the instrument controls to position the first back reflection for the thickness to be tested at least one half of the distance across the cathode ray tube.

8.2 Using the set of reference blocks spanning the thickness of the casting being inspected, mark the flat-bottom hole indication height for each of the applicable blocks on the cathode ray tube shield. Draw a curve through these marks on the screen or on suitable graph paper. The maximum signal amplitude for the test blocks used shall peak at approximately three-fourths of the screen height above the sweep by use of the attenuator. This curve shall be referred to as the 100% distance–amplitude correction (DAC) curve. If the attenuation of ultrasound in the casting thickness being examined is such that the system's dynamic range is exceeded, segmented DAC curves are permitted.

8.3 The casting examination surface will normally be rougher than that of the test blocks; consequently, employ a transfer mechanism to provide approximate compensation. In order to accomplish this, first select a region of the casting that has parallel walls and a surface condition representative of the rest of the casting as a transfer point. Next, select the test block whose overall length, *C* (Fig. 1), most closely matches the reflection amplitude through the block length. Place the search unit on the casting at the transfer point and adjust the instrument gain until the back reflection amplitude through the casting matches that through the test block. Using this transfer technique, the examination sensitivity in the casting may be expected to be within ±30% or less of that given by the test blocks.

8.4 Do not change those instrument controls and the test frequency set during calibration, except the attenuator, or calibrated gain control, during acceptance examination of a given thickness of the casting. Make a periodic calibration during the inspection by checking the amplitude of response from the $\frac{1}{4}$-in. (6.4-mm) diameter flat-bottom hole in the test block utilized for the transfer.

NOTE 3 — The attenuator or calibrated gain control may be used to change the signal amplitude during examination to permit small amplitude signals to be more readily detected. Signal evaluation is made by returning the attenuator or calibrated gain control to its original setting.

8.5 During examination of areas of the casting having parallel walls, recheck areas showing 75% or greater loss of back reflection to determine whether loss of back reflection is due to poor contact, insufficient couplant, misoriented discontinuity, etc. If the reason for loss of back reflection is not evident, consider the area questionable and further investigate.

9. Report

9.1 The manufacturer's report of final ultrasonic examination shall contain the following data and shall be furnished to the purchaser:

9.1.1 The total number, location, amplitude, and area when possible to delineate boundaries by monitoring the movement of the center of the search unit of all indications equal to or greater than 100% of the DAC,

9.1.2 Questionable areas from 8.5 that, upon further investigation, are determined to be caused by discontinuities,

9.1.3 The examination frequency, type of instrument, types of search units employed, couplant, manufacturer's identifying numbers, purchaser's order number, and data and authorized signature, and

9.1.4 A sketch showing the physical outline of the casting, including dimensions of all areas not inspected due to geometric configuration, with the location and sizes of all indications in accordance with 9.1.1 and 9.1.2.

10. Acceptance Standards

10.1 This practice is intended for application to castings with a wide variety of sizes, shapes, compositions, melting processes, foundry practices, and applications. Therefore, it is impractical to specify an ultrasonic quality level that would be universally applicable to such a diversity of products. Ultrasonic acceptance or rejection criteria for individual castings should be based on a realistic appraisal of service requirements and the quality that can normally be obtained in production of the particular type of casting.

10.2 Acceptance quality levels shall be established between the purchaser and the manufacturer on the basis of one or more of the following criteria:

10.2.1 No indication equal to or greater than the DAC over an area specified for the applicable quality level of Table 2.

10.2.2 No reduction of back reflection of 75% or greater that has been determined to be caused by a discontinuity over an area specified for the applicable quality level of Table 2.

10.2.3 Indications producing a continuous response equal to or greater than the DAC with a dimension exceeding the maximum length shown for the applicable quality level shall be unacceptable.

10.2.4 Other criteria agreed upon between the purchaser and the manufacturer.

10.3 Other means may be used to establish the validity of a rejection based on ultrasonic inspection.

NOTE 4 — The areas for the ultrasonic quality levels in Table 2 of Practice A 609/A 609M refer to the surface area on the casting over which a continuous indication exceeding the DAC is maintained.

NOTE 5 — Areas are to be measured from dimensions of the movement of the search unit by outlining locations where the amplitude of the indication is 100% of the DAC or where the back reflection is reduced by 75%, using the center of the search unit as a reference point to establish the outline of the indication area.

NOTE 6 — In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases, other criteria that incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

TABLE 2
REJECTION LEVEL

Ultrasonic Testing Quality Level	Area, in.^{2} [cm^2] (see 10.2.1 and 10.2.2)	Length, max, in. [mm]
1	0.8 [5]	1.5 [40]
2	1.5 [10]	2.2 [55]
3	3 [20]	3.0 [75]
4	5 [30]	3.9 [100]
5	8 [50]	4.8 [120]
6	12 [80]	6.0 [150]
7	16 [100]	6.9 [175]

Note 1—The areas in the table refer to the surface area on the casting over which a continuous indication exceeding the amplitude reference line or a continuous loss of back reflection of 75% or greater is maintained.
Note 2—Areas shall be measured from the center of the search unit.
Note 3—In certain castings, because of very long test distances or curvature of the test surface, the casting surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting; in such cases a graphic plot that incorporates a consideration of beam spread should be used for realistic evaluation of the discontinuity.

PROCEDURE B — BACK-WALL REFLECTION CALIBRATION PROCEDURE

11. Apparatus

11.1 Apparatus shall be kept on a regular six month maintenance cycle during which, as a minimum requirement, the vertical and horizontal linearities, sensitivity, and resolution shall be established in accordance with the requirements of Practice E 317.

11.2 *Search Units* — Ceramic element transducers not exceeding 1.25 in. [32 mm] diameter or 1 in.^{2} [645 mm^2] shall be used.

11.3 *Search Units Facing* — A soft urethane membrane or neoprene sheet, approximately 0.025 in. [0.64 mm] thick, may be used to improve coupling and minimize transducer wear caused by casting surface roughness.

11.4 *Calibration/Testing* — The same system, including the urethane membrane, used for calibration shall be used to inspect the casting.

11.5 *Other Inspections* — Other frequencies and type search units may be used for obtaining additional information and pinpointing of individual indications.

11.6 *Couplant* — A suitable liquid couplant, such as clean SAE 30 motor oil or similar commercial ultrasonic couplant, shall be used to couple the search unit to the test surface. Other couplants may be used when agreed upon between the purchaser and supplier.

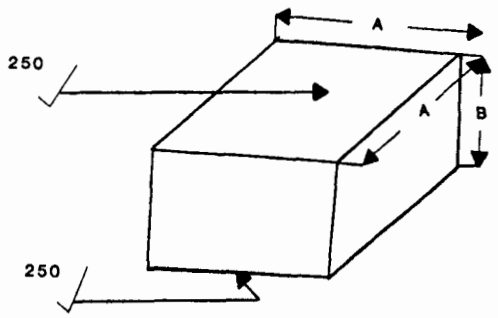
11.7 *Reference Standards* — Reference standards in accordance with Fig. 3 shall be used to calibrate the instrument for inspecting machined and cast surfaces. Reference standards shall be flaw free and machined within tolerances indicated.

12. Ultrasonic Instrument

12.1 *Type* — Pulsed ultrasonic reflection instrument capable of generating, receiving, and amplifying frequencies of 1 MHz to 5 MHz shall be used for testing.

12.2 *Voltage* — Line voltage shall be suitably regulated by constant voltage equipment and metal housing must be grounded to prevent electric shock.

12.3 *Linearity* — The instrument must provide a linear presentation (within ±5%) of at least 1.5 in. [40 mm] sweep to peak (S/P).



Dimensions, in. [mm]		Material
2 [50]	½ [13]	Specification A 217/A 217M, Grade WC6 or acoustically similar within ±20 % or 2 dB.
2 [50]	2 [50]	
3 [75]	5 [125]	
6 [150]	10 [250]	
Tolerance		

All sides to be flat within 0.0002 in. [0.01 mm] and parallel with 0.001 in. [0.03 mm].

FIG. 3 CALIBRATION BLOCKS

12.4 *Calibrated Gain Control of Attenuator* — The instrument shall contain a calibrated gain control or signal attenuator (accurate within ±10%) which will allow indications beyond the linear range of the instrument to be measured.

12.5 *Time-Corrected Gain* — The instrument shall be equipped to compensate for signal decay with distance. A method should be available to equalize signal response at different depths.

13. Qualification

13.1 The requirements for pre-production qualification are as follows:

13.1.1 *Personnel* — The personnel qualification requirements of SNT-TC-1A are applicable. Other personnel qualification requirement documents may be used when agreed upon between the purchaser and the supplier. Records of all personnel shall be available to customers upon request.

13.1.2 *Equipment* — The equipment shall be capable of meeting the requirements in Section 12.

14. Preparation

14.1 *Time of Inspection* — The final ultrasonic acceptance inspection shall be performed after at least an austenitizing heat treatment and preferably after machining. In order to avoid time loss in production, acceptance inspection of cast surfaces may be done prior to machining. Machined surfaces shall be acceptance inspected as soon as possible after machining. Repair welds may be inspected before the postweld heat treatment.

TABLE 3
ACCEPTANCE CRITERIA FOR SINGLE ISOLATED INDICATIONS

Quality Level	Maximum Nonlinear Indication, Area, in.^{2} [cm^2]	Position of Indication
1	0	E
2	1 [6]	E
3	1 [6]	O
	2 [13]	C
4	3 [19]	E
5	3 [19]	O
	5 [32]	C
6	5 [32]	E
7	5 [32]	O
	7 [45]	C
8	7 [45]	E
9	7 [45]	O
	9 [58]	C
10	9 [58]	E
11	9 [58]	O
	11 [71]	C

Note 1 — The area measured by movement of the center of the transducer over the casting surface.
Note 2 — O = outer wall ⅓, or inner wall ⅓.
C = midwall ⅓.
E = entire wall.

14.2 *Surface Finish:*

14.2.1 *Machined Surfaces* — Machined surfaces subject to ultrasonic inspection shall have a finish that will produce an ultrasonic response equivalent to that obtained from a 250 μin. (6.3 μm) surface. The surface finish shall also permit adequate movement of search units along the surface.

14.2.2 *Casting Surfaces* — Casting surfaces to be ultrasonically inspected shall be suitable for the intended type and quality level (Tables 3 and 4) of inspection as judged acceptable by a qualified individual as specified in 13.1.1.

14.2.3 *Surface Condition* — All surfaces to be inspected shall be free of scale, machining or grinding particles, excessive paint thickness, dirt, or other foreign matter that may interfere with the inspection.

14.3 *Position of Casting* — The casting shall be positioned such that the inspector has free access to the back wall for the purpose of verifying change in contour.

15. Calibration

15.1 *Calibration Blocks* — Determine the thickness of the material to be ultrasonically inspected. For material thickness of 3 in. [75 mm] or less, use the series of 3

TABLE 4
ACCEPTANCE CRITERIA FOR CLUSTERED INDICATIONS

Quality Level	Cumulative Area of Indications, in.^{2} [cm^2][A, B]	Minimum Area in Which Indications Must Be Dispersed, in.^{2} [cm^2][C]
1	0	0
2–3	2 [13]	36 [232]
4–5	4 [26]	36 [232]
6–7	6 [39]	36 [232]
8–9	8 [52]	36 [232]
10–11	10 [64]	36 [232]

[A] Regardless of wall location, that is midwall 1/3, innermost 1/3, or outermost 1/3.
[B] Each indication that equals or exceeds the 0.5-in. [18 mm] reference line shall be traced to the position where the indication is equal to 0.25 in. [6 mm]. The area of the location, for the purpose of this evaluation, shall be considered the area that is confined within the outline established by the center of the transducer during tracing of the flaw as required. Whenever no discernible surface tracing is possible, each indication which equals or exceeds the 0.5 in. reference amplitude shall be considered 0.15 in.^{2} [1 cm^2] (three times the area of the 1/4 diameter [6 mm] flat-bottomed hole to compensate for reflectivity degradation of natural flaw) for the cumulative area estimates.
[C] The indications within a cluster with the cumulative areas traced shall be dispersed in a minimum surface area of the casting equal to 36 in.^{2} [230 cm^2]. If the cumulative areas traced are confined with a smaller area of distribution, the area shall be repair welded to the extent necessary to meet the applicable quality level.

blocks, 1/2, 2, 5 in. [13, 50, 125 mm] (Fig. 3, B dimension) for calibration. For a material thickness greater than 3 in., use the series of 3 blocks, 2, 5, 10 in. [50, 125, 250 mm] (Fig. 3, B dimension) for calibration.

15.2 *Calibration of Search Units* — For the thickness of material to be inspected, as determined in 15.1, use the following search units:

15.2.1 For materials 3 in. [75 mm] or less in thickness, use a 2 1/4 MHz, 1/2 in. [13 mm] diameter search unit.

15.2.2 For material greater than 3 in. [75 mm] in thickness, use a 2 1/4 MHz, 1 in. [25 mm] diameter search unit.

15.3 *Calibration Procedure:*

15.3.1 Set the frequency selector as required. Set the reject control in the "OFF" position.

15.3.2 Position the search unit on the entrant surface of the block that completely encompasses the metal thickness to be inspected (Fig. 3) and adjust the sweep control such that the back reflection signal appears approximately, but not more than three-quarters along the sweep line from the initial pulse signal.

15.3.3 Position the search unit on the entrant surface of the smallest block of the series of 3 blocks selected for calibration and adjust the gain until the back reflection signal height (amplitude) is 1.5 in. [40 mm] sweep to peak (S/P). Draw a line on the cathode-ray screen (CRT), parallel to the sweep line, through the peak of the 1.5 in. (S/P) amplitude.

15.3.4 Position the search unit on the entrant surface of the largest block of the series of 3 blocks selected for calibration, and adjust the distance–amplitude control to provide a back reflection signal height of 1.5 in. [40 mm] (S/P).

15.3.5 Position the search unit on the entrant surface of the intermediate calibration block of the series of 3 blocks being used for calibration and confirm that the back reflection signal height is approximately 1.5 in. [40 mm] (S/P). If it is not, obtain the best compromise between this block and the largest block of the series of 3 blocks being used for calibration.

15.3.6 Draw a line on the cathode ray tube screen parallel to the sweep line at 0.5 in. [13 mm] (S/P) amplitude. This will be the reference line for reporting discontinuity amplitudes.

15.3.7 For tests on *machined surfaces*, position the search unit on a machined surface of casting where the walls are reasonably parallel and adjust the gain of the instrument until the back reflection signal height is 1.5 in. [40 mm] (S/P). Increase the inspection sensitivity by a factor of three times (10 dB gain) with the calibrated attenuator. Surfaces that do not meet the requirements of 14.2.1 shall be inspected as specified in 15.3.8.

15.3.8 For inspections on *cast surfaces*, position the search unit on the casting to be inspected at a location where the walls are reasonably parallel and smooth (inside and outside diameter) and the surface condition is representative of the surface being inspected. Adjust the gain of the instrument until the back reflection signal height is 1.5 in. [40 mm] (S/P). Increase the inspection sensitivity by a factor of six times (16 dB) by use of the calibrated control or attenuator. A significant change in surface finish requires a compensating adjustment to the gain.

15.3.8.1 Rejectable indications on as-cast surfaces may be reevaluated by surface preparation to 250 μin. [6.3 μm] finish or better, and reinspected in accordance with 15.3.7 of this practice.

15.3.8.2 It should be noted that some instruments are equipped with decibel calibrated gain controls, in which case the decibel required to increase the sensitivity must be added. Other instruments have decibel calibrated attenuators, in which case the required decibel must be removed. Still other instruments do not have calibrated gains or attenuators. They require external attenuators.

16. Scanning

16.1 *Grid Pattern* — The surface of the casting shall be laid out in a 12 by 12 in. [300 by 300 mm] or any similar grid pattern for guidance in scanning. Grid numbers shall be stenciled on the casting for record purposes and for grid area identity. The stenciled grid number shall appear in the upper right hand corner of the grid. When grids are laid out on the casting surface and they encompass different quality levels, each specific area shall be evaluated in accordance with the requirements of the specific quality level designated for that area.

16.2 *Overlap* — Scan over the surface allowing 10% minimum overlap of the working diameters of the search unit.

16.3 *Inspection Requirements* — All surfaces specified for ultrasonic (UT) shall be completely inspected from both sides, whenever both sides are accessible. The same search unit used for calibration shall be used to inspect the casting.

17. Additional Transducer Evaluation

17.1 Additional information regarding any ultrasonic indication may be obtained through the use of other frequency, type, and size search unit.

18. Acceptance Criteria

18.1 *Rejectable Conditions* — The locations of all indications having amplitudes greater than the 0.5 in. [13 mm] line given in 15.3.6, when amplitude three times (machined surfaces) or six times (cast surfaces) shall be marked on the casting surface. The boundary limits of the indication shall be determined by marking a sufficient number of marks on the casting surfaces where the ultrasonic signal equals one half the reference amplitude, 0.25 in. [6 mm]. To completely delineate the indication, draw a line around the outer boundary of the center of the number of marks to form the indication area. Draw a rectangle or other regular shape through the indication in order to form a polygon from which the area may be easily computed. It is not necessary that the ultrasonic signal exceed the amplitude reference line over the entire area. At some locations within the limits of the indication, the signal may be less than the reference line, but nevertheless still present such that it may be judged as a continuous, signal indication. Rejectable conditions are as follows and when any of the conditions listed below are found, the indications shall be removed and repair welded to the applicable process specification.

18.2 *Linear Indications* — A linear indication is defined as one having a length equal to or greater than three times its width. An amplitude of $\frac{1}{2}$ in. [13 mm], such as would result from tears or stringer type slag inclusion, shall be removed.

18.3 *Non-Linear Indications:*

18.3.1 *Isolated Indications* — Isolated indications shall not exceed the limits of the quality level designated by the customer's purchase order listed in Table 3. An isolated indication may be defined as one for which the distance between it and an adjacent indication is greater than the longest dimension of the larger of the adjacent indications.

18.3.2 *Clustered Indications* — Clustered indications shall be defined as two or more indications that are confined in a 1 in. [25 mm] cube. Clustered indications shall not exceed the limits of the quality level designated by the customer purchase order in Table 4. Where the distance between indications is less than the lowest dimension of the largest indication in the group, the cluster shall be repair welded.

18.3.3 The distance between two clusters must be greater than the lowest dimension of the largest indication in either cluster. If they are not, the cluster having the largest single indication shall be removed.

18.3.4 All indications, regardless of their surface areas as indicated by transducer movement on the casting surface and regardless of the quality level required, shall not have a through wall distance greater than $\frac{1}{3}T$, where T is the wall thickness in the area containing the indication.

18.3.5 Repair welding of cluster-type indications need only be the extent necessary to meet the applicable quality level for that particular area. All other types of rejectable indications shall be completely removed.

18.3.6 Repair welds of castings shall meet the quality level designated for that particular area of the casting.

18.3.7 Any location that has a 75% or greater loss in back reflection and exceeds the area of the applicable quality level, and whose indication amplitudes may or may not exceed the 0.5 in. [13 mm] rejection line, shall be rejected unless the reason for the loss in back reflection can be resolved as not being caused by an indication. If gain is added and back echo is achieved without indication percent amplitude exceeding the 0.5 in. [13 mm] rejection line, the area should be accepted.

19. Records

19.1 *Stenciling* — Each casting shall be permanently stenciled to locate inspection zones or grid pattern for ease in locating areas where rejectable indications were observed.

19.2 *Sketch* — A report showing the exact depth and surface location in relation to the stencil numbers shall be made for each rejectable indicator found during each inspection.

19.2.1 The sketch shall also include, but not be limited to, the following:

19.2.1.1 Part identification numbers,

19.2.1.2 Purchase order numbers,

19.2.1.3 Type and size of supplemental transducers used,

19.2.1.4 Name of inspector, and

19.2.1.5 Date of inspection.

20. Product Marking

20.1 Any rejectable areas (those indications exceeding the limits of Section 19) shall be marked on the casting as the inspection progresses. The point of marking shall be the center of the search unit.

21. Keywords

21.1 carbon and low-alloy steel; castings; martensitic stainless steel; ultrasonic

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall be applied only when agreed upon between the purchaser and the supplier to achieve an effective examination of a critical casting area that cannot be effectively examined using a longitudinal beam as a result of casting design or possible discontinuity orientation.

S1. Angle Beam Examination of Steel Castings

S1.1 *Equipment:*

S1.1.1 *Examination Instrument* — Examination shall be conducted with an ultrasonic, pulsed-reflection type of system generating frequencies of at least 0.4 to 5 MHz. Properties of the electronic apparatus shall be the same as those specified in 4.1.

S1.1.2 *Search Units* — Angle-beam search units shall produce an angle beam in steel in the range from 30 to 75° inclusive, measured to the perpendicular of the entry surface of the casting being examined. It is preferred that search units shall have frequency of 0.4 to 5 MHz.

S1.1.3 *Calibration Blocks* — A set of blocks, as shown in Fig. S1.1, with as cast surface equivalent to SCRATA Comparator A3 and of a thickness comparable to the sections being examined with side-drilled holes at $^1/_4t$, $^1/_2t$, and $^3/_4t$ (where t = thickness of the block) shall be used to establish an amplitude reference line (ARL).

S1.2 *Calibration of Equipment:*

S1.2.1 Construct the distance–amplitude correction curve by utilizing the responses from the side-drilled holes in the basic calibration block for angle beam examination as shown in Fig. S1.1 and Table S1.1.

S1.2.1.1 Resolve and mark the amplitudes of the $^1/_4t$ and $^1/_2t$ side-drilled holes from the same surface. The side-drilled hole used for the $^1/_4t$ amplitude may be used to establish the $^3/_4t$ amplitude from the opposite surface or a separate hole may be used.

S1.2.1.2 Connect the $^1/_4t$, $^1/_2t$, and $^3/_4t$ amplitudes to establish the applicable DAC.

S1.2.2 The basic calibration blocks shall be made of material that is acoustically similar to the casting being examined.

S1.2.3 Do not use basic calibration blocks with as cast surface equivalent to SCRATA Comparator A3 to examine castings with surface rougher than SCRATA Comparator A3. Use a machined calibration block for machined surfaces.

S1.2.4 The search unit and all instrument control settings remain unchanged except the attenuator or calibrated gain control.

S1.2.4.1 The attenuator or calibrated gain control may be used to change the signal amplitude during examination to permit small amplitude signals to be more readily detected. Signal evaluation is made by returning the attenuator or calibrated gain control to its original setting.

S1.3 *Data Reporting* — The supplier's report of final ultrasonic examination shall contain the following data:

S1.3.1 The total number, location, amplitude, and area of all indications equal to or greater than 100% of the distance–amplitude curve.

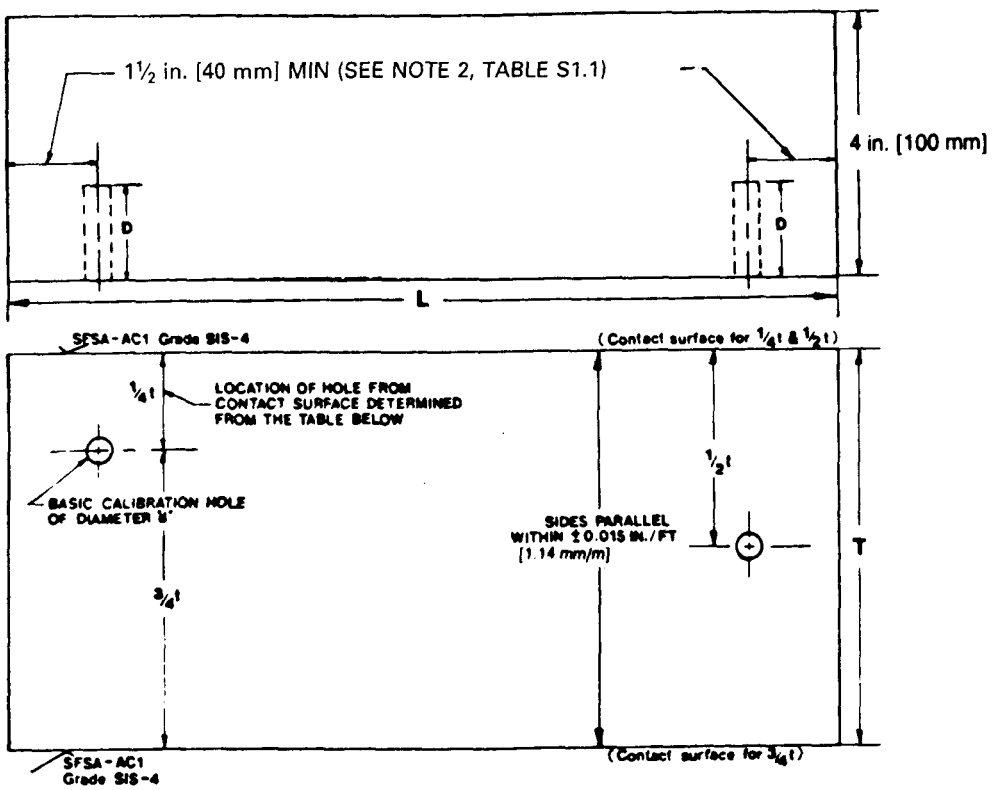
S1.3.2 The examination frequency, type of instrument, type and size of search units employed, couplant, transfer method, examination operator, supplier's identifying numbers, purchase order number, date, and authorized signature.

S1.3.3 A sketch showing the physical outline of the casting, including dimensions of all areas not examined due to geometric configuration, with the location of all indications in accordance with S1.3.1.

S1.4 *Acceptance Standards* — Acceptance quality levels shall be established between the purchaser and the manufacturer on the basis of one or more of the following criteria:

S1.4.1 No indication equal to or greater than the DAC over an area specified for the applicable quality level of Table 2.

S1.4.2 Other criteria agreed upon between the purchaser and the manufacturer.



L = length of block determined by the angle of search unit and the vee-path used,
T = thickness of basic calibration block (see Table S1.1),
D = depth of side-drilled hole (see Table S1.1),
d = diameter of side-drilled hole (see Table S1.1),
t = nominal production material thickness.

FIG. S1.1 BASIC CALIBRATION BLOCK FOR ANGLE-BEAM EXAMINATION

TABLE S1.1
DIMENSIONS OF CALIBRATION BLOCKS FOR ANGLE-BEAM EXAMINATION

Nominal Production Material Thickness (t), in. [mm]	Basic Calibration Block Thickness (T), in. [mm]	Hole Diameter (d), in. 1.002 [mm ± 0.05]	Minimum Depth (D), in. [mm]
Up to 1 [25] incl.	1 [25] or t	3/32 [2.4]	1½ [40]
Over 1 to 2 [25–50]	2 [50] or t	⅛ [3.2]	1½ [40]
Over 2 to 4 [50–100]	4 [100] or t	3/16 [4.8]	1½ [40]
Over 4 to 6 [100–150]	6 [150] or t	¼ [6.3]	1½ [40]
Over 6 to 8 [150–200]	8 [200] or t	5/16 [7.9]	1½ [40]
Over 8 to 10 [200–250]	10 [250] or t	⅜ [9.5]	1½ [40]
Over 10 [250]	t	See Note 1	1½ [40]

Note 1 — For each increase in thickness of 2 in. [50 mm], or a fraction thereof, the hole diameter shall increase 1/16 in. [1.6 mm].
Note 2 — For block sizes over 3 in. [75 mm] in thickness, T, the distance from the hole to the end of the block shall be ½T, min, to prevent coincident reflections from the hole and the corner. Block fabricated with a 2-in. [50-mm] minimum dimension need not be modified if the corner and hole indications can be easily resolved.

STANDARD PRACTICE FOR ULTRASONIC EXAMINATION OF AUSTENITIC STEEL FORGINGS

SA-745/SA-745M

(Identical with ASTM Specification A 745/A 745M-94)

1. Scope

1.1 This practice covers the standards and procedures for the contact, pulse-echo ultrasonic examination of austenitic steel forgings by the straight or angle beam techniques, or both.

1.2 This practice shall be used whenever the inquiry, proposal, contract, order, or specification states that austenitic steel forgings are to be subject to ultrasonic examination in accordance with Practice A 745/A 745M. Ultrasonic examination of nonmagnetic retaining ring forgings should be made to Practice A 531, not to this practice.

1.3 The values stated in either inch-pound or SI units are to be regarded as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the practice.

1.4 This practice and the applicable material specifications are expressed in both inch-pound units and SI units. However, unless the order specifies the applicable "M" specification designation (SI units), the material shall be furnished to inch-pound units.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 531/A 531M Practice for Ultrasonic Inspection of Turbine-Generator Steel Retaining Rings

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection

2.2 *American Society for Nondestructive Testing Document:*

SNT-TC-1A Recommended Practice for Nondestructive Personnel Qualification and Certification

3. Ordering Information

3.1 When this practice is to be applied to an inquiry or purchase order, the purchaser shall furnish the following information:

3.1.1 Quality level of examination (see Section 12).

3.1.2 Additional requirements to this practice.

3.1.3 Applicability of supplementary requirements (see Supplementary Requirements section).

3.2 When specified, the manufacturer shall submit an examination procedure for purchaser approval that shall include, but not be limited to, a sketch of the configuration as presented for ultrasonic examination showing the surfaces to be scanned, scanning directions, notch locations and sizes (if applicable), extent of coverage (if applicable), and an instruction listing calibration and inspection details and stage of manufacture.

4. Apparatus

4.1 An electronic, pulsed, reflection type of instrument shall be used for this examination. The system shall have a minimum capability for operating at frequencies

from 0.5 to 5.0 MHz. Either video or r-f presentation is acceptable.

4.2 The ultrasonic instrument shall provide linear presentation (within ±5% of the signal height) for at least 75% of the screen height (sweep line to top of screen). This 5% linearity is descriptive of the screen presentation of amplitude. Instrument linearity shall be verified in accordance with the intent of Practice E 317.

4.3 Instruments with incremental gain control (accurate over its useful range to ±10% of the nominal attenuation ratio) shall be used when possible to allow measurement of signals beyond the linear display range of the instrument.

4.4 *Search Units:*

4.4.1 Search units having transducers of either quartz or other piezoelectric materials may be employed.

4.4.2 The maximum nominal active area of $1\frac{1}{2}$ in.^{2} [970 mm^2] with $\frac{1}{2}$ in. [13 mm] minimum to $1\frac{1}{8}$ in. [30 mm] maximum dimensions or $\frac{3}{4}$-in. [20-mm] diameter minimum dimension shall be used for straight-beam scanning.

4.4.3 Angle-beam scanning transducers shall have a nominal active area of $\frac{1}{2}$ to 1 in.^{2} [325 to 650 mm^2]. The search unit used for angle-beam examination shall produce a beam angle of 30° to 70° in the material.

4.4.4 Other search units, including frequencies other than those listed in Section 8, may be used for evaluating and pinpointing indications of discontinuities.

4.5 *Couplant* — A suitable couplant having good wetting characteristics shall be used between the transducer and the examination surface. The same couplant shall be used for calibration and examination.

4.6 *Reference Blocks:*

4.6.1 All ultrasonic standard reference blocks shall be in accordance with the general guidelines of Practice E 428. However, absolute conformance to Practice E 428 is not mandatory due to the nature of the material covered by this practice.

4.6.2 The reference block grain size, as measured by the relative acoustic penetrability of the reference blocks, should be reasonably similar to the forging under examination. However, it must be recognized that large austenitic forgings vary considerably in acoustic penetrability throughout their volume due to variations in grain size and structure. Reference blocks should be chosen that reasonably approximate the average penetrability of the forging under examination. Supplementary blocks of coarser or finer grain may be used for evaluation of indications as covered in Section 11.

4.6.3 As an alternative method, where practicable, the appropriate size of reference hole (or holes) or notches may be placed in representative areas of the forging for calibration and examination purposes when removed by subsequent machining. When holes or notches are not removed by subsequent machining, the purchaser must approve the location of holes or notches.

5. Personnel Requirements

5.1 Personnel performing the ultrasonic examinations to this practice shall be qualified and certified in accordance with a written procedure conforming to Recommended Practice No. SNT-TC-1A or another national standard that is acceptable to both the purchaser and the supplier.

6. Forging Conditions

6.1 Forgings shall be ultrasonically examined after heat treating.

6.2 The surfaces of the forging to be examined shall be free of extraneous material such as loose scale, paint, dirt, etc.

6.3 The surface roughness of scanning surfaces shall not exceed 250 μin. [6 μm] unless otherwise stated in the order or contract.

6.4 The forgings shall be machined to a simple configuration, that is, rectangular or parallel or concentric surfaces where complete volumetric coverage can be obtained.

6.5 In certain cases, such as with contour forged parts, it may be impractical to assure 100% volumetric coverage. Such forgings shall be examined to the maximum extent possible. A procedure indicating the extent of examination coverage shall be submitted for the purchaser's approval (see 3.2).

7. Procedure

7.1 Perform the ultrasonic examination after heat treatment when the forging is machined to the ultrasonic configuration but prior to drilling holes, cutting keyways, tapers, grooves, or machining sections to final contour.

7.2 To ensure complete coverage of the forging volume when scanning, index the search unit with at least 15% overlap with each pass.

7.3 The scanning rate shall not exceed 6 in. [150 mm]/s.

7.4 Scan all regions of the forging in at least two perpendicular directions to the maximum extent possible.

7.5 Scan disk and disk-type forgings using a straight beam from at least one flat face and radially from the circumference when practicable. For the purposes of this practice, a disk is a cylindrical shape where the diameter dimension exceeds the height dimension. Disk-type forgings made as upset-forged "pancakes" shall be classified as disks for inspection purposes although at the time of inspection, the part may have a center hole, counterturned steps, or other detail configuration.

7.6 Scan cylindrical sections, ring and hollow forgings from the entire external surface (sides or circumference), using the straight-beam technique, and scan the forging in the axial direction to the extent possible. When the length divided by the diameter ratio (slenderness ratio) exceeds 6 to 1 (or axial length exceeds 24 in. [600 mm]), scan axially from both end surfaces to the extent possible. If axial penetration is not possible due to attenuation, angle-beam examination directed axially may be substituted in place of axial straight beam. Examine ring and hollow forgings having an outside-diameter to inside-diameter ratio of less than 2 to 1 and a wall thickness less than 8 in. [200 mm] by angle-beam techniques from the outside diameter or inside diameter, or both, using full node or half-node technique (see 10.1.2 and 10.1.3) as necessary to achieve either 100% volumetric coverage or the extent of coverage defined by an approved procedure (see 3.2).

8. Examination Frequency

8.1 Perform all ultrasonic examination at the highest frequency practicable (as specified in 8.1.1, 8.1.2, or 8.1.3) that will adequately penetrate the forging thickness and resolve the applicable reference standard. Include in the ultrasonic examination report the examination frequency used. Determine the test frequency at the time of actual examination by the following guidelines:

8.1.1 The nominal test frequency shall be 2.25 MHz. Use of this frequency will generally be restricted due to attenuation.

8.1.2 One megahertz is acceptable and will be the frequency generally applicable.

8.1.3 When necessary, due to attenuation, 0.5 MHz examination frequency may be used. The purchaser may request notification before this lower frequency is employed.

8.1.4 In the event that adequate penetration of certain regions is not possible even at 0.5 MHz, alternative nondestructive examination methods (such as radiography) may be employed to ensure the soundness of the forging by agreement between the purchaser and the manufacturer.

9. Straight-Beam Examination

9.1 *Method of Calibration:*

9.1.1 Perform calibration for straight-beam examination on the flat-bottom hole size determined by the applicable quality level (see Section 12).

9.1.2 Determine the calibration method by the test metal distance involved.

9.1.2.1 Thicknesses up to 6 in. [150 mm] may be examined using either the single-block or the distance-amplitude curve calibration method.

(*a*) *Single-Block Method* — Establish the test sensitivity on the reference standard representing the forging thickness. Drill flat-bottom holes normal to the examining surface, to midsection in material up to 1.5 in. [40 mm] in thickness and at least 0.75 in. [20 mm] in depth but no deeper than midsection in thicknesses from 1.5 to 6 in. [40 to 150 mm]. Make evaluations of indications at the estimated discontinuity depth at which they are observed using supplementary reference standards, if necessary.

(*b*) *Distance–Amplitude Curve Correction Method* — Establish the test sensitivity on the reference standard whose metal travel distance represents the greater metal travel distance of the part under examination, within ±1 in. [25 mm].

9.1.2.2 Examine thicknesses from 6 to 24 in. [150 to 600 mm] using the distance–amplitude calibration method. Calibration to ½ thickness test metal distance may be used provided examinations from two opposing surfaces are made.

9.1.2.3 For metal travel distances over 24 in. [600 mm], perform one of the following examinations:

(*a*) Perform a back-reflection examination from at least one surface to QL-5 (see 12.1.1) or to a purchaser-approved procedure (see 3.2).

(*b*) On hollow-round forgings with wall thicknesses less than 8 in. [200 mm], perform an axial angle-beam scan in place of the straight-beam scan from the end surfaces. Calibration for this scan may be established on the existing axial notches required for the circumferential scan or on transverse oriented notches installed specifically for axial angle beam.

9.2 *Calibration Procedure* — Over an indication-free area of the forging and with the proper test frequency,

adjust the amplitude of the back reflection to the maximum limit of vertical linearity of the instrument. The adjusted instrument sensitivity display shall be the primary calibration reference for both the single-block and multiple-block calibration methods. If, at this gain setting, the amplitude response from the flat-bottom hole in the longest calibration block is not equal to or greater than 0.5 in. [13 mm] sweep-to-peak, adjust the instrument gain further to obtain a 0.5 in. [13 mm] sweep-to-peak minimum response. To complete the distance–amplitude correction curve, determine the remaining points defining the shape of the curve at this adjusted gain setting and mark the curve on the shield of the cathode ray tube or plot on a graph. At least three blocks shall be used with test metal distances of 3 in. [75 mm] $\frac{1}{2}T$, and T. However, the distance between any of the test blocks shall be $1\frac{1}{2}$ in. [40 mm] minimum. If indications closer than 3 in. [75 mm] from the initial pulse must be evaluated, an additional block with $1\frac{1}{2}$ in. [40 mm] test metal distance shall be used. This is the fixed reference against which all indications shall be evaluated at the maximum obtainable response at whatever depth the indications are observed. This will constitute an acceptable examination if there are no indications exceeding the acceptance limits. In large forgings, it is expected that a portion of the distance–amplitude curve will be above the vertical linearity limits of the instrument. If an indication appears in this area, readjust the instrument through the use of a calibrated gain control or through recalibration to the initial calibration level to bring the appropriate portion of the presentation on screen for evaluation of that specific area.

NOTE 1 — When flat surfaced reference block calibration is used for examination of forgings with surface curvature, compensation for curvature shall be made and the method for curvature correction shall be a matter of agreement between the producer and the purchaser. For diameters 80 in. [2000 mm] and over, no correction factor is required.

10. Angle-Beam Examination

10.1 Ring and hollow round forgings, as defined in 7.6, shall be angle-beam examined from their outer periphery in both circumferential directions employing the following method of calibration:

10.1.1 Notches of 1.25 in. [30 mm] maximum surface length, with the length perpendicular to sound propagation; depth based on quality level (Section 12), either rectangular with a width not greater than twice its depth or 60° minimum to 75° maximum included angle, located in the forging so as to produce no interference with each other, shall be used as calibration standards.

10.1.2 Determine the response from the inside and outside diameter calibration notches with the search unit positioned to produce the maximum response from each notch. Adjust the sensitivity of the ultrasonic equipment so that the indication from the notch at the greatest test metal distance is at least 0.5 in. [13 mm] sweep-to-peak. Draw a straight line connecting the peaks of the responses obtained from the inside and outside diameter notches. This shall be the primary reference line. This procedure is considered full node calibration.

10.1.3 In the event that a response of at least 0.5 in. [13 mm] sweep-to-peak cannot be obtained from both the inside and outside diameter notches, calibrate from both the outer periphery (the outside diameter surface) and the inside diameter surface. Adjust the sensitivity of the ultrasonic equipment so that the indication from the notch in the opposite surface is at least 0.5 in. [13 mm] sweep-to-peak in magnitude. This procedure is considered half-node calibration. Axial angle beam may be substituted for straight beam from the end surfaces, when specified.

NOTE 2 — Long cylinders or cylinders with small inside diameters are difficult to examine from the inside diameter surface. Normally, neither inside diameters smaller than 18 in. [450 mm] nor long cylinders exceeding 36 in. [900 mm] in length are scanned from the inside diameter surface.

11. Evaluation of Material

11.1 Coarse-grained austenitic materials frequently display sweep noise, particularly when an examination is performed at high sensitivities. For this reason, it is important to critically scrutinize reportable and rejectable indications to determine whether they result from defects or grain structure. It is desirable to have several sets of calibration blocks with varying degrees of grain coarseness so that the attenuation of the defective area can be reasonably matched with a test block for a more accurate minimum defect size estimation. Due to the normal wide variation in attenuation throughout a given large austenitic forging, it is permissible to evaluate rejectable indications on the basis of alternative calibration blocks that compare more reasonably in attenuation to the defect area. It is also permissible to insert reference holes into representative areas of the forging itself, with the approval of the purchaser, to be used for calibration and evaluation of indications. Loss of back reflection results not only from internal discontinuities but also from coarse or nonuniform grain structures, variations in coupling, nonparallel reflecting surfaces, and other factors that must be considered before concluding that loss of back reflection resulted from discontinuities.

12. Quality Levels for Acceptance

12.1 One of the following quality levels may be specified by the purchaser:

12.1.1 *Straight Beam:*

12.1.1.1 Material producing an indication response whose maximized amplitude equals or exceeds 100% of the primary reference or distance–amplitude correction curve at the estimated discontinuity depth shall be considered unacceptable.

(*a*) *QL-1* — A distance–amplitude curve shall be based upon the amplitude response from No. 8 flat-bottom hole ($^{8}/_{64}$ in. [3 mm]).

(*b*) *QL-2* — A distance–amplitude curve shall be based upon the amplitude response from No. 16 flat-bottom hole ($^{16}/_{64}$ in. [6 mm]).

(*c*) *QL-3* — A distance–amplitude curve shall be based upon the amplitude response from No. 24 flat-bottom hole ($^{24}/_{64}$ in. [10 mm]).

(*d*) *QL-4* — A distance–amplitude curve shall be based upon the amplitude response from No. 32 flat-bottom hole ($^{32}/_{64}$ in. [13 mm]).

(*e*) *QL-5* — A back reflection examination shall be performed guaranteeing freedom from complete loss of back reflection accompanied by an indication of a discontinuity. For this purpose, a back reflection of less than 5% of full screen height shall be considered complete loss of back reflection.

12.1.1.2 The applicable quality level will necessarily vary with test metal distance, purchasers' requirements, and the type and size of forging involved. Large disks, rings, or solid forgings and complex forgings present extraordinary problems and quality level application shall be a matter of agreement between the manufacturer and the purchaser. For general guidance purposes, the following list of test metal distances versus quality level attainable is provided for general information.

(*a*) *QL-1* — Generally practical for thicknesses up to 3 in. [75 mm].

(*b*) *QL-2* — Generally practical for thicknesses up to 8 in. [200 mm].

(*c*) *QL-3* — Generally practical for thicknesses up to 12 in. [300 mm].

(*d*) *QL-4* — Generally practical for thicknesses up to 24 in. [600 mm].

(*e*) *QL-5* — Frequently practical for thicknesses over 24 in. [600 mm].

12.1.2 *Angle Beam* — Material producing indications with amplitudes equal to or exceeding the primary reference-acceptance line (full node calibration: see 10.1.2) at the estimated discontinuity depth observed shall be considered unacceptable. When examining with only one calibration notch (half node calibration: see 10.1.3), material containing indications of discontinuities equal to or exceeding the notch indication amplitude shall be considered unacceptable.

12.1.2.1 *QA-1* Angle beam reference acceptance shall be based on a notch depth of 3% of the thickness of the forging at the time of examination.

12.1.2.2 *QA-2* Angle beam reference acceptance line shall be based on a notch depth of the lesser of 5% of the thickness of the forging at the time of inspection, or $^{3}/_{4}$ in. [19.05 mm].

13. Reportable Indications

13.1 A record that shows the location and orientation of all indications or groups of indications with amplitudes as defined below shall be submitted to the purchaser for information.

13.1.1 Indications accompanied by a loss of back reflection of 75% of screen height. Similar loss in back reflection without indications shall be scanned at lower frequencies; if unsuccessful, the area shall be reported as "not inspected."

13.1.2 Indications distinct from the normal noise level and traveling to the left or right on the cathode ray tube with movement of the transducer 1.0 in. [25 mm] or more over the surface of the forging.

13.1.3 Indications equal to or exceeding 50% of the applicable reference acceptance curve (both straight and angle beam).

14. Keywords

14.1 acceptance criteria; austenitic forgings; contact method; ultrasonic examination

SUPPLEMENTARY REQUIREMENTS

Supplementary requirements shall apply only when specified by the purchaser in the inquiry or order. Details of these supplementary requirements shall be agreed upon between the manufacturer and the purchaser.

S1. Angle Beam Calibration Based on Final Thickness

S1.1 The depth of the calibration notch (see 12.1.2) shall be based upon the final ordered thickness of the forging rather than the thickness at the time of inspection.

A06

STANDARD METHOD FOR ULTRASONIC INSPECTION OF ALUMINUM-ALLOY PLATE FOR PRESSURE VESSELS

SB-548

(Identical with ASTM Specification B 548-03.)

1. Scope

1.1 This method covers pulse-echo ultrasonic inspection of aluminum-alloy plate of thickness equal to or greater than 0.500 in. (12.7 mm) for use in the fabrication of pressure vessels. The ultrasonic test is employed to detect gross internal discontinuities oriented in a direction parallel to the rolled surface such as cracks, ruptures, and laminations, and to provide assurance that only plate that is free from rejectable discontinuities is accepted for delivery.

1.2 The inspection method and acceptance criteria included in this standard shall be limited to plate of the following aluminum alloys: 1060, 1100, 3003, Alclad 3003, 3004, Alclad 3004, 5050, 5052, 5083, 5086, 5154, 5254, 5454, 5456, 5652, 6061, and Alclad 6061.

1.3 This method applies only to ultrasonic tests using pulsed longitudinal waves which are transmitted and received by a search unit containing either a single crystal or a combination of electrically interconnected multiple crystals. Ultrasonic tests employing either the through-transmission or the angle-beam techniques are not included.

1.4 This method shall be used when ultrasonic inspection as prescribed herein is required by the contract, purchase order, or referenced plate specification.

1.5 The values stated in inch-pound units are the standard. The SI values in parentheses are for information only.

1.6 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The following documents of the issue in effect on date of material purchase form a part of this specification to the extent referenced herein:

2.1.1 *ASTM Standards:*

E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method

E 214 Practice for Immersed Ultrasonic Examination by the Reflection Method Using Pulsed Longitudinal Waves

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments

2.1.2 *Other Standard:*

ASNT Recommended Practice for Nondestructive Testing Personnel Qualification and Certification — Ultrasonic Testing Method — SNT-TC-1A.

3. Summary of Method

3.1 The plate is inspected ultrasonically by scanning one rolled surface with a beam of pulsed longitudinal waves which is oriented in a direction perpendicular to the entry surface of the plate. The ultrasound is transmitted into the plate either by the direct contact, immersion, or liquid-column coupling method. During the scan, an indication representing the first back reflection is observed on the A-scan screen of the test instrument.

3.2 When the test system sensitivity level is appropriately adjusted, a discontinuity is detected during the scan by noting an isolated indication associated with a loss of the first back reflection indication. The apparent size of the discontinuity is determined by measuring the total area in the scanned entry surface of the plate where the isolated indication and the loss of back reflection persist. The estimated discontinuity size and location are then compared with suitable acceptance criteria.

NOTE 1 — Additional information describing ultrasonic tests by the direct contact method and by the immersion method is available in Practices E 114 and E 214.

4. Significance and Use

4.1 A number of factors such as the condition of the entry and back surfaces of the plate, the inclination of the ultrasonic beam with respect to the entry surface, and the performance characteristics of the test system may cause either a reduction of isolated indications or a substantial loss of back reflection and thereby could seriously impair the reliability of the test procedure outlined in this standard.

4.2 Accurate evaluations of discontinuity size also may be limited significantly by variations in beam characteristics which exist in most search units. For this reason, discontinuity size as determined by the test procedure outlined in this method is regarded as "apparent" or "estimated" in recognition of the limited quantitative value of the measurement.

4.3 Because a large number of interacting variables in a test system can adversely influence the results of an ultrasonic test, the actual quantitative effects of detected discontinuities upon the mechanical properties of the inspected plate are difficult to establish. Consequently, this ultrasonic inspection method is not applicable as an exclusive indicator of the ultimate quality and performance of pressure vessels but provides a reliable control of plate quality to avoid failure during the forming process for fabrication of vessels.

5. Apparatus

5.1 *Test Instrument* — Any electronic device that produces pulsed longitudinal waves and displays ultrasonic reflections on an A-scan indicator when used with an appropriate search unit is satisfactory. The instrument shall provide stable, linear amplification of received pulses at a selected test frequency and shall be free from significant interface signal interference at the required sensitivity level.

5.2 *Search Unit* — The search unit recommended for this standard is the flat nonfocusing type, and contains a piezoelectric crystal which generates and receives longitudinal waves at the rated frequency when connected to the test instrument through a suitable coaxial cable. A dual-crystal search unit containing both a transmitting and a receiving crystal in one container may be used provided the test instrument will accommodate two-crystal operation and the resulting pulse-echo test is equivalent to that obtained with a search unit containing a single-crystal.

5.2.1 The total effective area of the crystal or combination of crystals in the search unit used for initial scanning shall not be less than 0.4 in.^{2} (2.6 cm^2) nor greater than 3.0 in.^{2} (19.4 cm^2).

5.2.2 The effective diameter of the round search unit used to evaluate discontinuity size shall not exceed 0.75 in. (19 mm).

NOTE 2 — For control purposes, the performance characteristics of the test instrument and search unit may be established in accordance with procedures outlined in Practice E 317.

5.3 *Tank* — For tests by the immersion method, any container is satisfactory that will facilitate the accurate, stable positioning of both the search unit and the plate to be inspected.

5.4 *Scanning Apparatus* — During the inspection procedure, the search unit is supported by any one of the following devices. The scanning apparatus shall permit measurement of both the scan distance and the index distance within ± 0.1 in. (± 2 mm).

5.4.1 *Manipulator and Bridge* — When a manipulator is used in tests by the immersion method, the manipulator shall adequately support a search tube containing a search unit and shall provide fine adjustment of angle within 1° in two vertical planes that are perpendicular to each other. The bridge shall be of sufficient strength to provide rigid support for the manipulator and shall allow smooth, accurate positioning of the search unit. Special search unit supporting fixtures may be used provided they meet the requirements prescribed for a manipulator and bridge.

5.4.2 *Liquid Coupling Nozzle* — For tests by the liquid-column coupling method, the nozzle is usually positioned manually and shall be capable of containing the couplant while rigidly supporting the search unit with its active surface immersed in the couplant. The couplant distance shall be maintained so that the second couplant reflection is to the right of the first back reflection on the instrument cathode ray tube (CRT). The couplant path shall not vary more than ±1/4 in. (6.4 mm) during calibration, initial scanning, and discontinuity evaluation. The

recommended minimum inside dimension of the nozzle is 1.0 in. (25 mm) greater than the maximum dimension of the crystal surface in the search unit. Provisions also should be included for adjustment of search unit inclination within 1° in two vertical planes that are perpendicular to each other.

NOTE 3 — Nozzles containing either sealed or unsealed openings may be used for inspecting plate provided the test results obtained with either device are equivalent to those obtained by the immersion method.

5.4.3 *Contact Scanning Unit* — During tests by the contact method, the search unit usually is supported and positioned manually on the entry surface of the inspected plate. However, special fixtures for contact scanning may be employed provided their use ensures conformance to the requirements in this specification.

5.5 *Couplant* — Clean, deaerated water at room temperature is the recommended couplant for tests either by the immersion method or by the liquid-column coupling technique. Inhibitors or wetting agents or both may be used. For tests by the contact method, the recommended couplant is clean, light-grade oil.

NOTE 4 — Other coupling liquids may be employed for inspecting plate provided their use does not adversely affect test results.

6. Personnel Requirements

6.1 The testing operator performing the ultrasonic examination prescribed in this standard shall be qualified and certified to at least a Level I — Ultrasonic Testing in accordance with the ASNT Recommended Practice SNT-TC-1A.

6.2 The required documentation supporting qualification and certification of ultrasonic testing operators shall be established by the certifying agency and shall be available upon request by the purchaser.

7. Condition of Plate

7.1 The entry and back surfaces of the inspected plate shall be sufficiently clean, smooth, and flat to maintain a first back reflection amplitude greater than 50% of the initial standardization amplitude while scanning an area in the plate that does not contain significant isolated ultrasonic discontinuities.

7.2 The inspected plate shall be at room temperature during the test.

8. Procedure

8.1 *Preferred Method* — The ultrasonic test may be performed by either the liquid column coupling, the direct contact, or the immersion methods. However, the immersion method is preferred.

8.1.1 Maintain the couplant distance so that the second couplant reflection is to the right of the first back reflection on the instrument's A-scan display. The couplant path shall not vary more than ±¼ in. (6.4 mm) during calibration, initial scanning, and discontinuity evaluation.

8.2 *Test Frequency* — When using any of the three methods listed in 8.1, the recommended test frequency is 5.0 MHz. Other test frequencies between 2.0 MHz and 10.0 MHz may be employed when necessary to minimize possible adverse effects of plate thickness, microstructure, and test system characteristics upon test results and thereby maintain a clean, easily interpreted A-scan screen pattern throughout the inspection.

8.3 *Sensitivity Standardization* — Standardize the sensitivity level of the test system operating at the selected frequency by adjusting the instrument gain control to obtain a first back reflection amplitude of 75 ± 5% of the vertical limit exhibited by the A-scan indicator when the search unit is positioned over an area free from significant discontinuities in the plate to be inspected. During tests by either the immersion method or the liquid column coupling method, adjust the angular alignment of the search unit to obtain a maximum number of back reflections before the final sensitivity level is established.

8.4 *Scanning* — With no further adjustments of the instrument gain controls, locate the search unit over one corner of the plate to be inspected so that the edge of the crystal in the search unit is about 1 in. (25 mm) from either edge of the plate.

8.4.1 Subsequent to checking the angular alignment of the search unit with respect to the rolled entry surface to ensure a maximum first back reflection, proceed to scan the plate continuously by moving the search unit at a constant scanning rate (see 8.6) from the initial starting position to the opposite edge in a direction perpendicular to the predominant rolling direction of the plate.

8.4.2 During the scan, note the occurrence of isolated discontinuity indications and monitor the amplitude of the first back reflection by continuously observing the A-scan indicator screen.

NOTE 5 — Auxiliary monitoring devices may be employed in the test system to enhance detection reliability during the scan.

8.5 *Scan Index* — When the initial scan is completed, move the search unit over a predetermined scan index distance in a direction parallel to the predominant rolling direction of the plate and proceed with a second scan along a line parallel to the initial scanning direction while

observing the test pattern on the A-scan indicator screen. Calculate the scan index distance as follows:

$$\text{Scan index distance (in.), } S_i = 0.8 + 0.7\ D_s$$

$$\text{Scan index distance (mm), } S_i = 20 + 0.7\ D_s$$

where:

D_s = actual crystal diameter.

8.5.1 Continue the inspection by constantly observing the test pattern on the A-scan indicator while successively scanning the plate at a constant scanning rate in a direction perpendicular to the predominant rolling direction of the plate and indexing the search unit through the index distance calculated in 8.5.

8.5.2 During the inspection procedure, check the test system sensitivity standardization periodically by noting the amplitude of the first back reflection when the search unit is repositioned over the reference area of the plate and by adjusting the instrument gain control as required to maintain the sensitivity standardization specified previously in 8.3.

8.6 *Scanning Rate* — When the screen pattern on the A-scan indicator is monitored visually by the test operator during the inspection, the scanning rate shall not be greater than 12 in./s (305 mm/s).

NOTE 6 — Scanning rates greater than 12 in./s (305 mm/s) may be employed if auxiliary monitoring apparatus is used to maintain adequate detection reliability.

8.7 *Detection of Discontinuities* — When an isolated ultrasonic indication of amplitude greater than 30% of the A-scan vertical limit is encountered or when the first back reflection indication decreases to an amplitude less than 5% of the vertical limit at any time during the inspection procedure, stop the scan and angulate the search unit to obtain a maximum isolated indication and to determine that the loss of back reflection is not caused by misalignment of the search unit with respect to the plate.

8.7.1 To ensure that the loss of back reflection is not caused by surface interference, check the condition of both the entry and back surfaces of the plate at the location where a substantial (95% or greater) loss of back reflection occurs.

8.7.2 Either a maximized isolated ultrasonic indication exhibiting an amplitude greater than 50% of the amplitude of the initial first back reflection used for standardization, or a substantial loss of the first back reflection indication not attributable to either search unit misalignment or surface interference, is an indication of an internal discontinuity.

NOTE 7 — Isolated indications occurring midway between the entry surface indication and the first back reflection may cause a second indication at the location of the first back reflection on the A-scan screen. When this condition is verified by checking the multiple back reflection pattern, a complete loss of the first back reflection can be assumed.

8.8 *Estimation of Discontinuity Size* — Note the location of the search unit where the scan was stopped when either an isolated indication or a loss of back reflection was observed.

8.8.1 Using a search unit containing a crystal of effective diameter no greater than 0.75 in. (19 mm), make an evaluation scan of an entire 6-in. (152-mm) square area which is centered around the point on the plate entry surface where the scan was discontinued. The recommended index distance for this evaluation is as follows:

$$S_i \text{ (in. or mm)} = 0.7\ D_s$$

where:

D_s = actual diameter of the search unit crystal.

8.8.2 To determine the apparent size of the discontinuity, mark each location corresponding to the center of the search unit on the plate entry surface where a 95 ± 5% loss of first back reflection is observed or where the isolated indication exhibits an amplitude equal to 50 ± 5% of the amplitude of the initial first back reflection established during the standardization procedure outlined in 8.3.

8.8.3 Continue to mark the location of the search unit at each point where either or both of the discontinuity conditions specified in paragraph 8.8.2 are observed. The entire discontinuity shall be outlined even if it extends beyond the original 6-in. (152-mm) square evaluation scan area.

8.8.4 The estimated discontinuity size is the area defined by the boundary consisting of successive marks as established by this procedure.

NOTE 8 — Automatic recording devices may be used to establish the estimated size of a discontinuity provided the recorded results are equivalent to those obtained by the procedure presented in 8.8.

8.9 When the estimated size of a detected discontinuity is determined, return the search unit to the original stopping position and continue the initial scan to complete the inspection.

9. Acceptance Standards

9.1 Upon completing the inspection procedure, measure the longest dimension of each marked area representing a detected discontinuity. Also, when an engineering

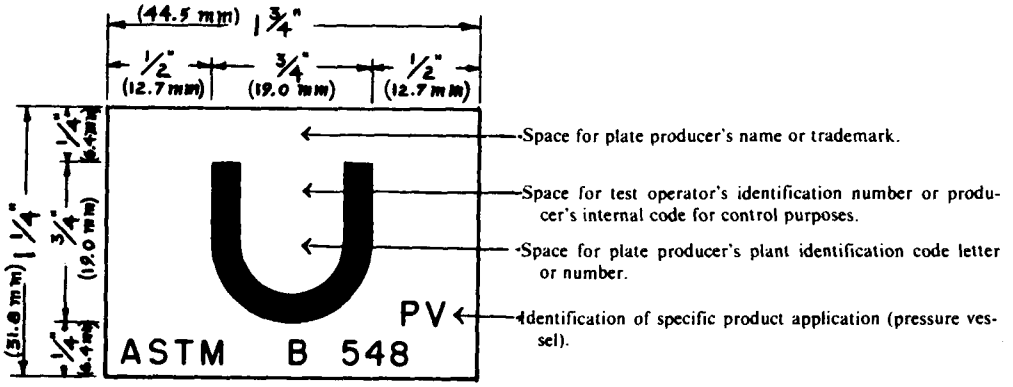


FIG. 1 STAMP FOR IDENTIFYING ACCEPTABLE PLATE

drawing showing the part to be fabricated from the plate is supplied, compare the locations of the discontinuities with the dimensions on the drawing.

9.2 If the longest dimension of the marked area representing a discontinuity causing a complete loss of back reflection (95% or greater) exceeds 1.0 in. (25 mm), the discontinuity is considered to be significant and the plate shall be subject to rejection.

9.3 If the length of the marked area representing a discontinuity causing an isolated ultrasonic indication without a complete loss of back reflection (95% or greater) exceeds 3.0 in. (76 mm), the discontinuity is considered to be significant and the plate shall be subject to rejection.

9.4 If each of two marked areas representing two adjacent discontinuities causing isolated ultrasonic indications without a complete loss of back reflection (95% or greater) is longer than 1.0 in., and if they are located within 3.0 in. of each other, the proximity between the two discontinuities is considered to be significant, and the plate shall be subject to rejection.

NOTE 9 — A template containing a 1.0-in. diameter hole and a 3.0-in. diameter hole is a convenient device for rapidly establishing the significance of discontinuities. If the discontinuities described in 9.2 and 9.3 cannot be totally enclosed within either the 1.0-in. diameter circle or the 3.0-in. diameter circle, respectively, then the plate containing such discontinuities shall be subject to rejection. Similarly, if any portions of two adjacent discontinuities greater than 1.0 in. in length as in accordance with 9.4 appear within the 3.0-in. diameter circle, the plate shall be subject to rejection.

9.5 A plate containing significant discontinuities of rejectable size shall be acceptable if it is established by the purchaser that the discontinuities will be removed from the plate by machining during the subsequent fabrication process.

9.6 Upon specific consent of the purchaser, a plate with significant discontinuities may be accepted if repaired by welding.

10. Report

10.1 When required by the purchaser, a report shall be prepared and shall include the date of test and a list of parameters including the type (model number) of instrument and search unit, the test method, frequency, and the couplant employed for the inspection.

10.2 Preparation of a drawing showing the location of all significant discontinuities in the inspected plate is recommended when the ultimate rejection or acceptance of the plate is to be determined by negotiation between the manufacturer and the purchaser.

10.3 The identification of an acceptable plate is desirable and is recommended. For this purpose, a suitable stamp should be employed to indicate conformance to this ultrasonic standard. The recommended stamp for identifying acceptable plate is shown in Fig. 1.

STANDARD PRACTICE FOR ULTRASONIC PULSE-ECHO STRAIGHT-BEAM EXAMINATION BY THE CONTACT METHOD

SE-114.2

[Identical with ASTM Specification E 114-95 (R2001)]

1. Scope

1.1 This practice covers ultrasonic examination of materials by the pulse-echo method using straight-beam longitudinal waves introduced by direct contact of the search unit with the material being examined.

1.2 This practice shall be applicable to development of an examination procedure agreed upon by the users of the document.

1.3 The values stated in inch-pound units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Examination Systems Without the Use of Electronic Measurement Instruments

E 543 Practice for Agencies Performing Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Standards:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Other Documents:*

NAS-410 NAS Certification & Qualification of Nondestructive Test Personnel

3. Terminology

3.1 Refer to Terminology E 1316 for definitions of terms used in this practice.

4. Basis of Application

4.1 *Purchaser-Supplier Agreements* — The following items require agreement between the using parties for this practice to be used effectively:

4.1.1 *Qualification of Nondestructive Testing Agencies* — Agreement is required as to whether the nondestructive testing agency, as defined in Practice E 543 must be formally evaluated and qualified to perform the examination. If such evaluation and qualification is specified, a documented procedure such as Practice E 543 shall be used as the basis for evaluation.

4.1.2 *Personnel Qualification* — Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, or a similar document. The practice or standard used and its applicable revision shall be specified in the contractual agreement between the using parties.

4.1.3 *Extent of Examination* — The extent of the examination shall be determined by agreement of the using parties.

4.1.4 *Time of Examination* — The time of examination shall be determined by agreement of the using parties.

4.1.5 *Interpretation Criteria* — The criteria by which the ultrasonic signals and part acceptability will be evaluated and shall be determined by agreement of the using parties.

5. Significance and Use

5.1 A series of electrical pulses is applied to a piezoelectric element (transducer) which converts these pulses to mechanical energy in the form of pulsed waves at a nominal frequency. This transducer is mounted in a holder so it can transmit the waves into the material through a suitable wear surface and couplant. The assembly of transducer, holder, wearface, and electrical connnector comprise the search unit.

5.2 Pulsed energy is transmitted into materials, travels in a direction normal to the contacted surface, and is reflected back to the search unit by discontinuity or boundary interfaces which are parallel or near parallel to the contacted surface. These echoes return to the search unit, where they are converted from mechanical to electrical energy and are amplified by a receiver. The amplified echoes (signals) are usually presented in an A-scan display, such that the entire round trip of pulsed energy within the resolution of the system may be indicated along the horizontal base line of the display by vertical deflections corresponding to echo amplitudes from each interface, including those from intervening discontinuities. By adjustment of the sweep (range) controls, this display can be expanded or contracted to obtain a designated relation between the displayed signals and the material reflectors from which the signal originates. Thus a scaled distance to a discontinuity and its displayed signal becomes a true relationship. By comparison of the displayed discontinuity signal amplitudes to those from a reference standard, both location and estimated discontinuity size may be determined. Discontinuities having dimensions exceeding the size of the sound beam can also be estimated by determining the amount of movement of a search unit over the examination surface where a discontinuity signal is maintained.

NOTE 1 — When determining the sizes of discontinuities by either of these two practices, only the area of the discontinuity which reflects energy to the search unit is determined.

5.3 Types of information that may be obtained from the pulsed-echo straight-beam practice are as follows:

5.3.1 Apparent discontinuity size (Note 2) by comparison of the signal amplitudes from the test piece to the amplitudes obtained from a reference standard.

5.3.2 Depth location of discontinuities by calibrating the horizontal scale of the A-scan display.

5.3.3 Material properties as indicated by the relative sound attenuation or velocity changes of compared items.

5.3.4 The extent of bond and unbond (or fusion and lack of fusion) between two ultrasonic conducting materials if geometry and materials permit.

NOTE 2 — The term "apparent" is emphasized since true size depends on orientation, composition, and geometry of the discontinuity and equipment limitations.

6. Apparatus

6.1 Complete ultrasonic apparatus shall include the following:

6.1.1 *Instrumentation* — The ultrasonic instrument shall be capable of generating, receiving, and amplifying high-frequency electrical pulses at such frequencies and energy levels required to perform a meaningful examination and to provide a suitable readout.

6.1.2 *Search Units* — The ultrasonic search units shall be capable of transmitting and receiving ultrasound in the material at the required frequencies and energy levels necessary for discontinuity detection. Typical search unit sizes usually range from $\frac{1}{8}$ in. (3.2 mm) in diameter to $1\frac{1}{8}$ in. (28.6 mm) in diameter with both smaller and larger sizes available for specific applications. Search units may be fitted with special shoes for appropriate applications. Special search units encompassing both a transmitter and a receiver as separate piezoelectric elements can be utilized to provide some degree of improved resolution near the examination surface.

6.1.3 *Couplant* — A couplant, usually a liquid or semiliquid, is required between the face of the search unit and the examination surface to permit or improve the transmittance of ultrasound from the search unit into the material under test. Typical couplants include water, cellulose gel, oil, and grease. Corrosion inhibitors or wetting agents or both may be used. Couplants must be selected that are not detrimental to the product or the process. The couplant used in standardization should be used for the examination. During the performance of a contact ultrasonic examination, the couplant layer between search unit and examination material must be maintained such that the contact area is held constant while maintaining adequate couplant thickness. Lack of couplant reducing the effective contact area or excess couplant thickness will reduce the amount of energy transferred between the search unit and the examination piece. These couplant variations in turn result in examination sensitivity variations.

TABLE 1
SUGGESTED VISCOSITIES — OIL COUPLANTS

Approximate Surface Roughness Average (Ra), μin. (μm)	Equivalent Couplant Viscosity, Weight Motor Oil
5–100 (0.1–2.5)	SAE 10
50–200 (1.3–5.1)	SAE 20
100–400 (2.5–10.2)	SAE 30
250–700 (6.4–17.8)	SAE 40
Over 700 (18–)	cup grease

Note — The table is a guide only and is not meant to exclude the use of a particular couplant that is found to work satisfactorily on a particular surface.

6.1.3.1 The couplant should be selected so that its viscosity is appropriate for the surface finish of the material to be examined. The examination of rough surfaces generally requires a high-viscosity couplant. The temperature of the material's surface can change the couplant's viscosity. As an example, in the case of oil and greases, see Table 1.

6.1.3.2 At elevated temperatures as conditions warrant, heat-resistant coupling materials such as silicone oils, gels, or greases should be used. Further, intermittent contact of the search unit with the surface or auxiliary cooling of the search unit may be necessary to avoid temperature changes that affect the ultrasonic wave characteristics of the search unit. At higher temperatures, certain couplants based on inorganic salts or thermoplastic organic materials, high-temperature delay materials, and search units that are not damaged by high temperatures may be required.

6.1.3.3 Where constant coupling over large areas is needed, as in automated examination, or where severe changes in surface roughness are found, other couplants such as liquid gap coupling will usually provide a better examination. In this case, the search unit does not contact the examination surface but is separated by a distance of about 0.2 in. (0.5 mm) filled with couplant. Liquid flowing through the search unit fills the gap. The flowing liquid provides the coupling path and has the additional advantage of cooling the search unit if the examination surface is hot.

6.1.3.4 An alternative means of direct contact coupling is provided by the wheel search unit. The search unit is mounted at the required angle to a stationary axle about which rotates a liquid-filled flexible tire. A minimum amount of couplant provides ultrasonic transmission into the examination surface since the elastic tire material is in rolling contact and conforms closely to the surface.

6.1.4 *Reference Standards* — The production item itself may be an adequate standard using the height of the back wall echo for reference. For more quantitative information, machined artificial reflectors (discontinuities) or charts representing distance-amplitude relationships of known reflector sizes for a particular search unit and material may be used for standardization. These artificial reflectors may be in the form of flat-bottom holes, side-drilled holes, or slots. An alternate method of fabricating a reference standard may be the introduction of known discontinuities during the fabrication process of a production item or other convenient configuration. The surface finish of the reference standard should be similar to the surface finish of the production item (or corrected; see 7.3). The reference standard material and the production material should be acoustically similar (in velocity and attenuation). The reference standard selected shall be used by the examiner as the basis for signal comparisons.

7. Standardization of Apparatus

7.1 If quantitative information is to be obtained, vertical or horizontal linearity or both should be checked in accordance with Practice E 317 or another procedure approved by the users of the document. An acceptable linearity performance may be agreed upon by the users of the document.

7.2 Prior to examination, standardize the system in accordance with the product specification.

7.3 Where the surface finishes of the reference standard and the production item do not match, or where there is an acoustic difference between the standard and the production item, an attenuation correction should be made to compensate for the difference. The attenuation correction is accomplished by noting the difference between signals received from the same reference reflector (that is, back reflection) in the basic standardization (reference) block and in the production material, and correcting for this difference.

7.4 It should be recognized that near-field effects may cause sensitivity inconsistencies when searching for inhomogeneities smaller than the effective beam diameter. Suitable delay line search units or other means such as examining from both sides of the item may be considered where the application warrants fine scrutiny. When performing examinations in the far-field, it is recommended that compensation be made for the acoustic attenuation of the test material with respect to a certain reference standard. This compensation may be accomplished with multiple depth reference reflectors, electronically, with

attenuation curves drawn on the face of the A-scan display, or with charts for distance-amplitude relationships of known reflectors. For optimum examination performance, compensations should be made for both near and far-field effects.

7.5 Unless otherwise specified, the initial pulse and at least one back reflection shall appear on the A-scan display while examining for discontinuities in materials having parallel surfaces. The total number of back reflections depends upon equipment, geometry and material type, information desired, or operator preference. Reduction of the back reflection during scanning is indicative of increased attenuation or sound scattering discontinuities provided that front and back surface roughness and parallelism of the production piece are approximately the same as that of the standard. For non-parallel surfaces, the time trace of the display shall be standardized by using standards that include the maximum thickness of the production item being examined.

7.6 For bond/unbond (fusion/lack of fusion) examinations, a reference standard should be used similar to the production item being examined containing areas representing both bonded (fused) and unbonded (lack of fusion) conditions, if geometry and material permit.

7.7 Standardization with respect to reference standards should be periodically checked to ensure that the ultrasonic system standardization is not changing. As a minimum, the standardization shall be checked each time there is a change of operators, when search units are changed, when new batteries are installed, when equipment operating from one power source is changed to another power source, or when improper operation is suspected.

8. Procedure

8.1 When ultrasonic examinations are performed for the detection or sizing of discontinuities, or both, reflectors not perpendicular to the ultrasonic beam may be detected at reduced amplitudes, with a distorted envelope depending upon the reflector area, whether it is curved or planar, whether it is smooth or rough, perhaps with reflecting facets. Reflector characteristics may also cause rapid shifts in apparent depth as the search unit approaches or moves away from the low amplitude indication. Another effect of these reflectors is the loss of back reflection which occurs when the discontinuity lies directly between the search unit and the back surface. Reflectors detectable due to any of the foregoing phenomena cannot be sized solely on signal amplitude but require special corrections for search unit and flaw characteristics.

8.2 *Examination Surface* — Surfaces shall be uniform and free of loose scale and paint, discontinuities such as pits or gouges, weld splatter, dirt, or other foreign matter which affect examination results. Tightly adhering paint, scale, or coatings do not necessarily need to be removed for examining if they present uniform attenuation characteristics. The examination surface must be adequate to permit ultrasonic examination at the sensitivity specified. If needed, surfaces may be ground, sanded, wire brushed, scraped, or otherwise prepared for examining purposes. Curved surfaces, either concave or convex, may be examined; however, the standardization system should compensate for the effective change in search unit transmitting area between the reference standard and production item. If practical, the reference standard should have the same geometry as the item being examined.

8.3 *Search Unit* — Select a suitable search unit size and frequency after consideration of the acoustic characteristics of material to be examined, the geometry of the production item, and the minimum size and type of discontinuity to be detected. The higher the frequency selected, the higher the resolving capability accompanied with a decrease in penetrating power; conversely, the lower the frequency used, the greater the penetrating power with decreasing resolving capability. Factors limiting the use of higher frequencies are the equipment and the material properties. The limiting use of lower frequencies is the loss in sensitivity level for the examination. Various types of straight-beam search units are available offering advantages for specific applications. The above statements should be considered when choosing the search unit size, type, and frequency. When delay materials are used in the search unit, the standardization and examination surface temperatures should be within 25°F (14°C) to avoid large attenuation and velocity differences.

NOTE 3 — The largest diameter and highest frequency search units yielding desired results should be used for maximum resolution and good beam directivity.

8.4 *Scanning* — Scanning may be either continuous or intermittent, depending upon the geometry, application, and requirements of the part being examined. For continuous scanning, the search unit indexing must be adequate to provide 100% coverage, at uniform examination sensitivity, of the area being examined. Adjust scanning speed or instrument repetition rate or both to permit detection of the smallest discontinuities referenced in the specification and to allow the recording or signaling device to function.

8.4.1 *Manual Scanning* — Hold the search unit in the hand and move over the surface of the production piece.

8.4.2 *Automated Scanning* — The search unit is held by a suitable fixed device and either the production piece moves or is held stationary while the search unit moves mechanically along some predetermined path. For automated scanning, monitor coupling between the search unit and part either electronically or visually to ensure proper examination sensitivity.

8.5 During the evaluation of indications, maintain the same relative sensitivities between the reference standard and the production item. Make an evaluation of ultrasonic indications after response reflections from discontinuities are maximized by search unit manipulation. Map discontinuity extremities larger than the sound beam. A recommended method for mapping, on the surface of the production piece, the apparent size (that is, the reflecting surface seen by the search unit) of discontinuities larger than the search unit is by the half-amplitude method. Position the search unit over the discontinuity for maximum signal response and move in one direction until the signal drops rapidly to the base line on the A-scan display. Then return the search unit to the position where the signal was half the amplitude that it had at the point where the indication began to drop rapidly to the base line. At this point the center of the search unit should approximately coincide with the edge of the discontinuity. Repeat this procedure for other directions as necessary to outline the discontinuity on the surface. Search units of other frequencies and sizes may be used for mapping to obtain greater accuracy. Special consideration should be given to discontinuities when the signal amplitude drops to half the maximum amplitude or less, and remains at the lower level over extended distances (for example, more than half the search unit diameter).

NOTE 4 — For rounded surfaces, geometry must be considered when using this method.

9. Examination Data Record

9.1 The following data should be recorded as a minimum for future reference at the time of each examination:

9.1.1 Part number identification,

9.1.2 Operator's name and level (if certified),

9.1.3 Instrument description, make, model, and serial number,

9.1.4 Setup — Couplant, cable type and length, manual/automatic scanning,

9.1.5 Search unit description — Type, size, frequency, special shoes,

9.1.6 Reference standards (and standardization data required to duplicate the examination).

9.1.7 Indication information as specified by the applicable specification, or results of the examination (number, classification, and location of discontinuities). For bond/unbond (fusion/lack of fusion) examinations the extent of unbond (lack of fusion) or bond (fusion) should be reported.

10. Interpretation of Results

10.1 Advance agreement should be reached by users of this document as applicable regarding the interpretation of the results of the examinations and how they shall be recorded. All discontinuities having signals that exceed the rejection level as defined by the material specification, drawing, or purchase order shall be rejected unless it is determined from the machine part drawing that the rejectable discontinuities will not remain in the finished part.

11. Report

11.1 The report shall include the information agreed upon by users of this document.

12. Keywords

12.1 contact; examination; nondestructive testing; pulse-echo; straight-beam; ultrasonic

STANDARD PRACTICE FOR ULTRASONIC EXAMINATION OF METAL PIPE AND TUBING

SE-213

(Identical with ASTM Specification E 213-98)

1. Scope

1.1 This practice covers a procedure for detecting discontinuities in metal pipe and tubing using pulse-reflection ultrasonic contact or immersion angle beam techniques. Artificial discontinuities consisting of longitudinal reference notches are employed as the primary means of standardizing the ultrasonic system. If transverse as well as longitudinal examination is desired, a procedure for employing transverse notches is provided.

1.2 This practice is intended for use with tubular products having outside diameters approximately ½ in. (12.7 mm) and larger, provided that the examination parameters comply with and satisfy the requirements of Section 12. These procedures have been used successfully for smaller sizes, however, and may be specified upon contractual agreement between the using parties.

NOTE 1 **Cautions** — Exercise caution when examining pipe or tubes near or below the ½-in. specified limit. Certain combinations of search unit size, frequency, *thin* wall thicknesses, and small diameters could cause generation of unwanted sound waves that may produce erroneous test results.

1.3 This practice does not establish acceptance criteria; they must be specified by the using party or parties.

1.4 The values stated in inch-pound units are to be regarded as standard. The SI equivalents are in parentheses and may be approximate.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Evaluating Agencies That Perform Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Documents:*

Recommended Practice SNT-TC-1A for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

3. Terminology

3.1 *Definitions* — For definitions of terms used in this practice, see Terminology E 1316.

4. Summary of Practice

4.1 A pulsed ultrasonic angle beam by either the surface contact or immersion method shall be used. Figure 1 illustrates the characteristic angle beam sound entry into the pipe wall for both contact and immersion testing using a single search unit.

NOTE 2 — Immersion test method may include tanks, wheel search units, or systems that use liquid streams.

4.2 Variations of the single search unit method using multiple search units with the same or various angles and special gating are sometimes desirable and may be necessary for efficient examination of thicker wall material.

5. Significance and Use

5.1 The purpose of this practice is to outline a procedure for detecting and locating significant discontinuities such as pits, voids, inclusions, cracks, splits, and the like, by the ultrasonic pulse-reflection method.

6. Basis of Application

6.1 The following are items that must be decided upon by the using party or parties.

6.1.1 Size and type of tubing to be examined.

6.1.2 Extent of examination, that is, scanning in one or both circumferential directions, scanning in one or both axial directions, weld zone only if welded, pitch of feed helix during scanning, etc.

6.1.3 The point(s) in the manufacturing process at which the material will be examined.

6.1.4 Surface condition.

6.1.5 Maximum time interval between equipment standardization checks, if different from that described in 13.2.

6.1.6 Type, dimensions, location, method of manufacture, and number of artificial discontinuities to be placed on the reference standard.

6.1.7 Method(s) for measuring dimensions of artificial discontinuities and tolerance limits if different than specified in Section 11.

6.1.8 Criteria for reportable and rejectable indications (that is, acceptance criteria).

6.1.9 Reexamination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

6.1.10 Requirements for permanent records of the response from each tube, if applicable.

6.1.11 Contents of testing report.

6.1.12 Operator qualifications and certification, if required.

6.1.13 Qualification of nondestructive agencies. If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in E 543. The applicable edition of E 543 shall be specified in the contractual agreement.

6.1.14 Level of personnel qualification (see 7.1).

7. Personnel Qualification

7.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

8. Surface Condition

8.1 All surfaces shall be clean and free of scale, dirt, grease, paint, or other foreign material that could interfere with interpretation of test results. The methods used for cleaning and preparing the surfaces for ultrasonic examination shall not be detrimental to the base metal or the surface finish. Excessive surface roughness or scratches can produce signals that interfere with the test.

9. Apparatus

9.1 The instruments and accessory equipment shall be of the pulse-reflection type and shall be capable of distinguishing the reference notches described in Section 11 to the extent required in the standardization procedure described in Section 12. Figure 1 illustrates the refraction of sound in the pipe or tube wall, and the circumferential direction of ultrasonic energy propagation used to detect longitudinal notches.

10. Couplant

10.1 A liquid couplant such as water, oil, or glycerin, capable of conducting ultrasonic vibrations between the transducer and the pipe or tube being tested shall be used. Rust inhibitors, softeners, and wetting agents may be added to the couplant. The couplant liquid with all additives should not be detrimental to the surface condition of the pipe or tube, and shall wet the surface of the material to provide adequate coupling efficiency.

NOTE 3 — In contact testing, some couplants result in better ultrasonic transmission when the tubing is precoated several hours before the test.

11. Reference Standards

11.1 A reference standard of a convenient length shall be prepared from a length of pipe or tube of the same nominal diameter, wall thickness, material, surface finish, and heat treatment as the material to be examined. The reference pipe or tube shall be free of discontinuities or other conditions producing indications that can interfere with detection of the reference notches.

11.2 Longitudinal (axial) reference notches shall be introduced on the outer and inner surfaces of the standard.

NOTE 4 — For sizes below 1/4-in. inner diameter, the ratio of the outer diameter to wall thickness must be taken into consideration.

11.3 If two or more reference notches are placed on the same end of the reference standard, they shall be separated sufficiently (circumferentially or axially or both) to preclude interference and interpretation difficulties.

11.4 All upset metal, burrs, etc., adjacent to the reference notches shall be removed.

11.5 The notch dimensions, which are length, depth, and width (and for V-notches, the included angle) must be decided upon by the using party or parties. Figure 2 illustrates the common notch configurations and the dimensions to be measured (Note 5). Reflection amplitudes from V-, square-, and U-shaped notches of comparable dimensions may vary widely depending on the angle, frequency, and vibrational mode of the interrogating sound beam.

NOTE 5 — In Figure 2 (*a*), (*b*), and (*d*), the sharp corners are for ease of illustration. It is recognized that in normal machining practice, a radius will be generated.

11.5.1 The notch depth shall be an average measured from the circular tubing surface to the maximum and minimum penetration of the notch. Measurements may be made by optical, replicating, or other agreed upon techniques. Notch depth shall be within ±0.0005 in. (0.013 mm) of the specified value for notches 0.005 in. (0.13 mm) or less in depth, and within +10, −15% of the specified value for notches over 0.005 in. in depth.

NOTE 6 — For as-rolled or scaly tube surfaces, it may be necessary to modify 11.5.1. Two acceptable modifications are listed below. Modification (*a*) is preferred; however, modification (*b*) may be used unless otherwise specified.

(*a*) The circular tube surface may be smoothed or prepared in the notch area, or

(*b*) The notch depth shall be within ±0.001 in. (0.025 mm), or +10, −15% of the specified depth, whichever is greater.

11.5.2 The width of the notches shall be as small as practical, but should not exceed twice the depth.

11.6 Other types and orientations of reference discontinuities may be specified by the using party or parties.

12. Standardization of Apparatus

12.1 Using the reference standard specified in Section 11, adjust the equipment to produce clearly identifiable indications from both the inner and outer surface notches. The relative response from the inner and outer surface notches should be as nearly equal as possible. Use the lesser of the two responses to establish the rejection level. On large diameter or heavy wall pipe and tubing, if the inner and outer surface notch amplitude cannot be made equal because of test metal distance and inside diameter curvature, a separate rejection level may be established for the inner and outer surface notches.

NOTE 7 — Indication amplitude may not be proportional to notch depth.

12.2 Standardize the equipment under dynamic conditions that simulate the production examination. The pipe or tubing to be examined and the search unit assembly shall have a rotating translating motion relative to each other such that a helical scan path will be described on the outer surface of the pipe or tube. Maintain the speed of rotation and translation constant within ±10%. Axial scanning with circumferential indexing may be used to provide equivalent coverage.

12.3 The pitch of the feed helix shall be small enough to ensure 100% coverage at the test distance and sensitivity established during calibration.

13. Procedure

13.1 Unless otherwise specified, examine the pipe or tubing with the ultrasound transmitted in one circumferential direction under the identical conditions used for equipment standardization (Note 8). Examination may be required with the ultrasound transmitted in both circumferential directions (see Supplementary Requirement S1). If the examination is to be performed in both directions, conduct the standardization procedure of Section 12 in both directions.

NOTE 8 — Identical conditions include all instrument settings, mechanical motions, search unit position and alignment relative to the pipe or tube, liquid couplant, and any other factors that affect the performance of the examination.

13.2 Periodically check standardization of the equipment by passing the reference standard through the examination equipment. Make these checks prior to any examination run, prior to equipment shutdown after an examination run, and at least every 4 h during continuous equipment operation. Restandardize the equipment in accordance with Section 12 any time the equipment does not present a clearly defined, rejectable signal from both the inner and outer surface notches of the standard.

13.3 For many tubular sizes and examination arrangements, there will be a reflection from the entry surface of the pipe or tube. This signal may be observed, but not gated, as a supplement to the required checking of the reference standard to give increased assurance that the equipment is functioning properly. If such a signal does not exist, make more frequent equipment standardization checks.

13.4 In the event that the equipment does not present signals as outlined in 12.1 and 13.2, reinspect all pipe or tubing examined since the last acceptable standardization after restandardization has been accomplished.

13.5 Do not make any equipment adjustments unless the complete standardization procedure described in Section 12 is performed.

13.6 The examination shall be applied to 100% of the pipe or tubing unless otherwise specified.

NOTE 9 — Some traversing mechanisms do not allow examination of tubing ends. When this condition exists, clearly indicate the extent of this effect, per tube, in the examination report.

14. Interpretation of Results

14.1 All indications that are equal to or greater than the rejection level established during standardization as described in Section 12, or as specified by the using party or parties, shall be considered as representing defects and may be cause for rejection of the pipe or tube.

14.2 If, upon examination of the pipe or tube, no rejectable indications are detected, the material shall be considered as having passed the ultrasonic examination, except as noted in 13.4.

NOTE 10 — Rejected pipe or tubes may be reworked in a manner acceptable to the purchaser. If, upon ultrasonic reexamination of the reworked pipe or tube, no rejectable indications are detected, the material should be considered as having passed the ultrasonic examination.

NOTE 11 — Care should be exercised to ensure that reworking a pipe or tube does not change its acceptability with respect to other requirements of the material specification such as wall thickness, ovality, surface finish, length, and the like.

15. Report

15.1 When a report is required, it shall contain such information as is mutually considered adequate to document that the pipe or tubes supplied meet the requirements of this practice.

16. Keywords

16.1 angle beam; nondestructive examination; pipe; tubing; ultrasonic examination

SUPPLEMENTARY REQUIREMENTS

These requirements shall apply only when individually specified by the using party or parties. When details of these requirements are not covered herein, they may be subject to agreement by a using party.

S1. Scanning

S1.1 Scanning shall be conducted with the ultrasonic beam directed in both circumferential directions.

S2. Distance–Amplitude Correction

S2.1 A method of compensating for the reduction in ultrasonic signal amplitude as a function of test metal distance shall be employed. Details of the procedures used to establish and apply the distance–amplitude correction (DAC) curve shall be established by the using party or parties.

S3. Transverse Notches

S3.1 Instead of (or in addition to) the longitudinal notches described in Section 11, a transverse (circumferential) notch shall be introduced on the inner and outer surfaces of the reference standard. The requirements of 11.3, 11.4, and 11.5 shall apply to transverse notches.

S3.2 An independent channel of instrumentation (including search unit assembly) shall be employed for the purpose of detecting transverse discontinuities.

S3.3 When transverse notches are required, the using party or parties shall also determine whether scanning is required in one or both axial directions. Figure 3 illustrates the refraction of sound in the pipe or tube wall, and the axial propagation of ultrasonic energy to detect transverse notches.

NOTE 12 — If a requirement exists for both longitudinal and transverse notches, and scanning for each in two directions, the following three options are available:

(a) Each pipe or tube is passed through a single-channel examination station four times, twice in each direction,

(b) Each pipe or tube is passed through a two-channel examination station twice, once in each direction, or

(c) Each pipe or tube is passed through a four-channel examination station once.

S4. Recording

S4.1 A permanent record containing objective evidence of the examination results shall accompany each accepted pipe or tube. This may be in the form of a strip chart recording of the ultrasonic instrument output during the examination. It shall contain recordings of all standardizations and standardization checks and shall be annotated to provide a positive correlation between each test record and the corresponding pipe and tube.

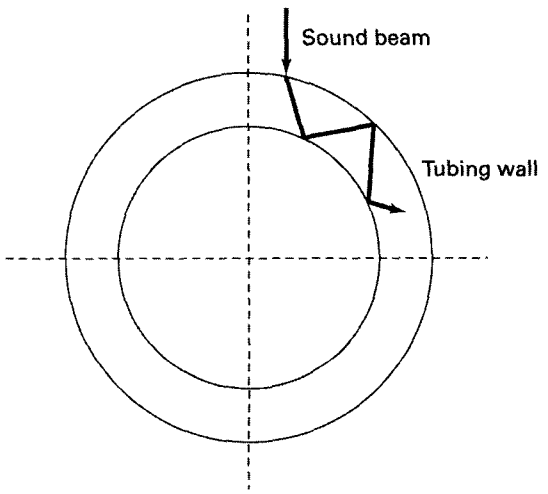


FIG. 1 CIRCUMFERENTIAL PROPAGATION OF SOUND IN TUBE WALL

S5. Report

S5.1 The supplier shall submit to the purchaser a report that includes at least the following information:

S5.1.1 Identification of the material by type, size, lot, heat, and the like.

S5.1.2 Identification of the examination equipment and accessories.

S5.1.3 Details of the examination technique, including examination speed, testing frequency, and end effects if any (Note 12).

S5.1.4 Description of the reference standard, including the actual (measured) dimensions of the artificial discontinuities.

S5.1.5 Description of the distance–amplitude correction procedure, if used. (See Supplementary Requirement S2.)

S5.1.6 Examination results.

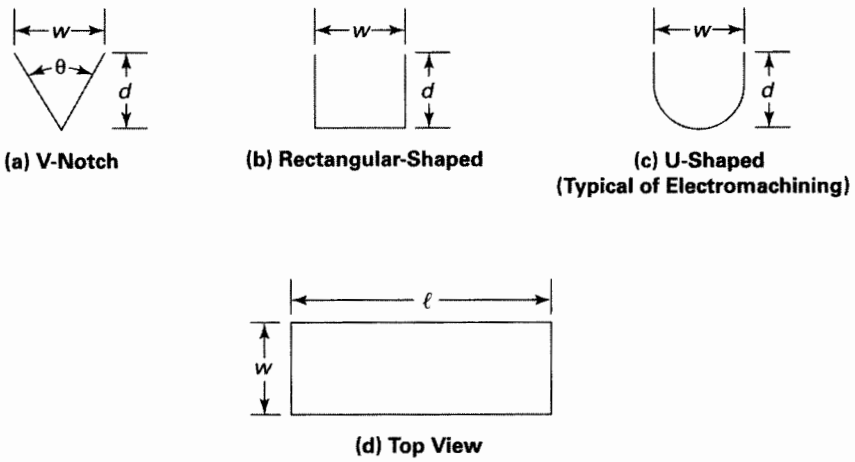


FIG. 2 COMMON NOTCH SHAPES

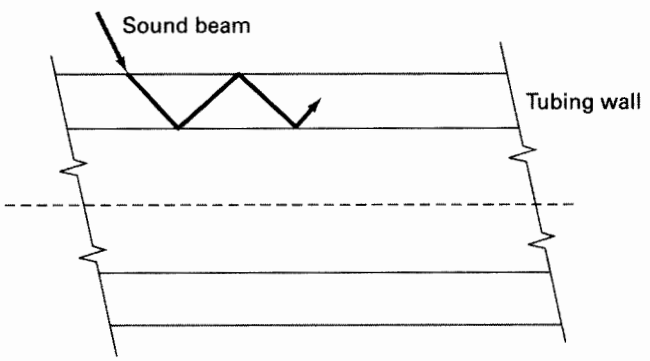


FIG. 3 AXIAL PROPAGATION OF SOUND IN TUBE WALL

STANDARD PRACTICE FOR ULTRASONIC EXAMINATION OF LONGITUDINAL WELDED PIPE AND TUBING

SE-273

(Identical with ASTM Specification E 273-93)

1. Scope

1.1 This practice describes general ultrasonic test procedures for the detection of discontinuities in the weld and adjacent heat affected zones of pipe and tubing. It is intended for tubular products having diameters ≥ 2 in. (≥ 50 mm) and wall thicknesses of $\frac{1}{8}$ to $1\frac{1}{16}$ in. (3 to 27 mm).

1.2 This practice does not establish acceptance criteria; they must be specified by the using parties.

NOTE 1 — Precautions should be exercised when testing pipes or tubes near the lower specified limits. Certain combinations of search unit size, frequency, thin wall thicknesses, and small diameters could cause generation of unwanted sound waves that may produce erroneous test results.

1.3 The values stated in inch-pound units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Evaluating Agencies That Perform Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions* — For definitions of terms used in this practice, see Terminology E 1316.

4. Summary of Practice

4.1 Angle projection of pulsed ultrasonic beam by either the surface contact or immersion method shall be used. Figure 1 illustrates the characteristic oblique sound entry into the pipe wall for both contact and immersion testing using a single search unit.

NOTE 2 — Immersion test method may include tanks, wheel search units, or bubbler systems.

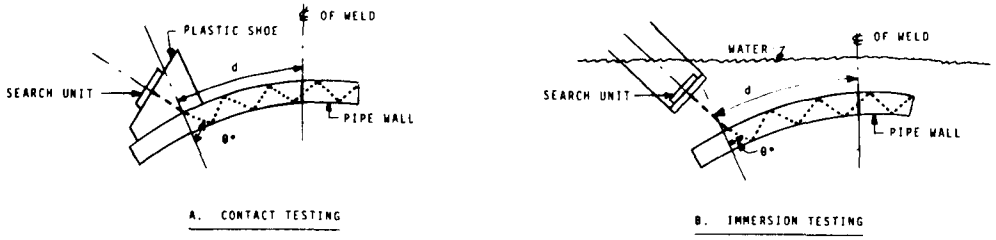
4.2 Variations of the single search unit method using multiple search units with the same or various angles and special gating are sometimes desirable and may be necessary for efficient examination of thicker wall material.

5. Apparatus

5.1 The instruments and accessory equipment shall be capable of producing, receiving, amplifying, and displaying electrical pulses at frequencies and pulse rates deemed necessary by the using parties. They shall be capable of distinguishing the reference reflectors described in Section 7 to the extent required in the calibration procedure outlined in Section 8.

5.2 For pulse echo test systems, the contact or immersion search units should produce ultrasonic waves that travel in the pipe or tube wall at a refracted angle of from 35° to 70° and perpendicular to the weld seam. For pitch/catch or through transmission test systems, orientation of the entry sound beam other than perpendicular to the weld seam may be required.

5.3 *Couplant* — A liquid such as water, oil, glycerin, etc., capable of conducting ultrasonic vibrations from the



NOTE—θ = 35° through 70°.

FIG. 1 ANGLE PROJECTION OF ULTRASONIC WAVE

transducer to the pipe or tube shall be used. Rust inhibitors, softeners, and wetting agents may be added to the couplant. The couplant liquid with all additives should not be detrimental to the surface condition of the pipe or tubing and should wet the surface. In the testing of electric-resistance-welded pipe, water-soluble oil used in cooling the pipe serves as a satisfactory couplant.

5.4 *Distance Amplitude Compensation* — The use of electronic methods to compensate for attenuation losses as a function of ultrasonic metal travel distance may be employed.

6. Basis of Application

6.1 The following are items that require decision for use of this practice:

6.1.1 Acceptance criteria.

6.1.2 Type, dimension, and number of reference reflectors to be placed in the reference standard.

6.1.3 Standardization of test sensitivity intervals.

6.1.4 Operator qualifications.

6.1.5 Qualification of NDT agency (as defined in Practice E 543), if required. Practice E 543 may be used for this agency qualification.

6.1.6 Test frequency.

6.1.7 Pulse repetition rate.

6.1.8 Sound beam orientation and number of beams used.

6.1.9 Procedure and use of distance amplitude compensation.

6.1.10 Reporting of test results.

7. Personnel Qualification

7.1 The ultrasonic examination shall be performed by qualified personnel. Qualification shall be based on a documented program that certifies personnel capable of conducting ultrasonic weld examinations.

8. Reference Standards

8.1 A reference standard, of sufficient length to allow verification of system calibration, shall be prepared from a length of pipe or tubing of the same nominal diameter and wall thickness, material, surface finish, and nominal heat treatment as the material to be examined. The pipe or tube selected for this purpose shall be free of discontinuities or other abnormal conditions that can cause interference with the detection of the reference reflectors. The reference reflectors shall be selected to ensure uniform coverage of the weld at the sensitivity levels prescribed. The reference reflectors most commonly used will consist of machined notches and drilled holes as described in paragraph 8.2. All upset metal, burrs, etc., adjacent to the reference reflectors, shall be removed.

8.1.1 *Electric Resistance-Welded or Butt-Welded Pipe* — Reference reflectors may be placed in the weld seam or in the pipe body and parallel to the weld seam. When longitudinal notches are used as reference reflectors, they shall be placed on the outer and inner surfaces of the reference standard and separated by some distance to ensure that the response from one reflector does not interfere with that from the other.

8.1.2 *Fusion-Welded Pipe* — The reference reflectors shall be placed in the weld. When longitudinal notches are used as reference reflectors, they shall be placed in the crown of the fusion-weld bead as shown in Fig. 2(*a*). In fusion-welded pipe containing both inside and outside surface weld beads, a longitudinal notch reference reflector shall be placed in the weld-bead crown on both the outside and inside surfaces.

8.1.2.1 When drilled holes are employed, they shall be drilled radially from both the outside and inside surfaces through 50% of the wall thickness at the weld-bead crown and separated by some distance that guarantees a distinct and separate response from each one [see Figs. 2(*c*) and 2(*d*)]. A hole drilled radially 100% through the pipe wall may be used instead of the 50% drilled hole [see Fig. 2(*e*)].

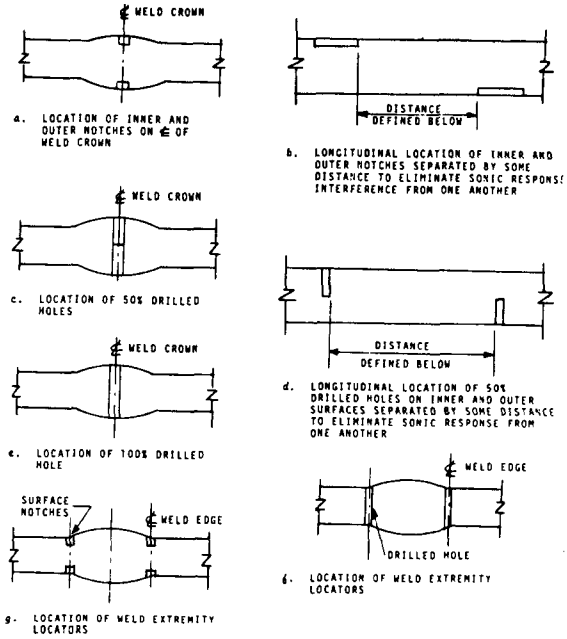


FIG. 2 TYPICAL NOTCH LOCATIONS FOR FUSION WELDED PIPE

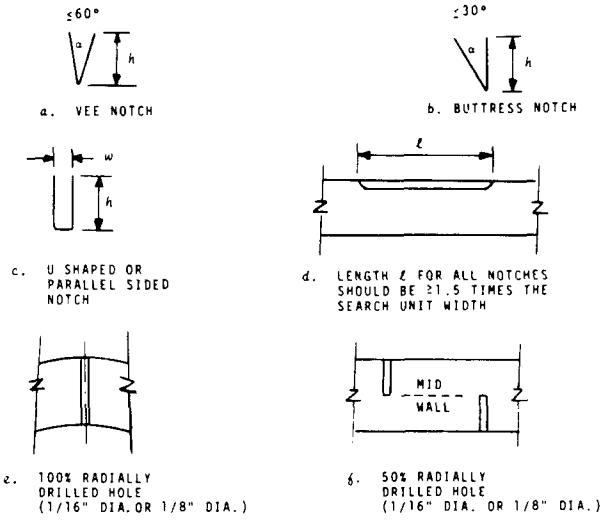


FIG. 3. COMMON REFERENCE REFLECTORS

8.1.2.2 Additional reflectors may be used to define weld extremities. Holes shall be drilled radially 100% through the pipe wall at the weld edges. As an alternative, longitudinal notches shall be placed at the edges of each weld [see Fig. 2(*f*)]. The weld-edge drilled holes or notches shall be separated by some distance to ensure that the response from one reflector does not interfere with that from another [see Fig. 2(*g*)]. The weld-edge reflectors are solely for the purpose of defining the position of the weld extremities and are not to be used for amplitude standardization.

8.2 The notch dimension of length, decided depth, width, and for Figs. 3(*a*) and 3(*b*) the included angle α must be decided upon by the using party or parties. Figure 3 illustrates the commonly accepted notch configurations and the dimensions to be measured.

8.2.1 The notch depth (*h*) shall be measured from the adjacent surface to its maximum and minimum penetration. Measurements may be made by optical, replicating or mechanical, or other techniques. Notch depth is commonly specified as a percent of nominal wall thickness with typical values being 10, 12½, or 20%. A ±15% tolerance is allowable on notch depths.

8.2.2 The length of the notch is considered to be the dimension where the depth of 8.2.1 is satisfied. It is preferred that the notch length (*l*) be ≥ 1.5 times the transducer element size.

8.2.3 The width (*w*) of the notch has negligible effect on calibration and is not a critical dimension.

8.2.4 Typical diameters for drilled holes are 1/16 in. (1.6 mm) and 1/8 in. (3.2 mm).

9. Standardization of Test Sensitivity

9.1 Using the reference standard specified in 8.1, the equipment shall be adjusted to produce readily distinguished and clearly identifiable indications from both the inner and outer reference reflectors. The relative response to the inner and outer reflectors shall be as near equal as possible. The lesser of the two responses shall be used as the acceptance level.

NOTE 3 — Adjustment of water path, adjustment of distance (*d*) in Fig. 1 and angulation of the beam have been used to achieve equality.

9.2 The test sensitivity shall be standardized and adjusted to produce clearly identifiable indications from both the outer and inner reference reflectors when the reference standard is scanned in a manner simulating the production examination of the pipe or tubing.

9.3 The equipment shall be adjusted to produce clearly identifiable responses from the weld-edge reflector and the reference reflector when the reference standard is scanned in a manner simulating the production examination of the pipe or tubing.

10. Examination Procedure

10.1 All surfaces shall be clean from scale, dirt, burrs, slag, spatter, or other conditions that will interfere with the test results.

10.2 Move the pipe or tubing past the search unit with the weld in a fixed position with respect to the search unit. Movement of the search unit with respect to a stationary pipe is satisfactory. During examination, maintain distance (*d*) and angle θ in Fig. 1 and the water path for immersion testing as determined during adjustment of the test sensitivity.

10.3 Certain testing systems using multiple search units or multiple beam transducers compensate for distance (*d*) changes and do not require strict adherence to the maintenance of this dimension during examination.

10.4 Periodically check the test sensitivity of the equipment by running the reference standard through the examination system. Make these checks prior to any pipe or tubing examination, prior to equipment shutdown after examination and at least every four hours during continuous equipment operation. Any time the equipment does not present a clearly defined signal within 10% of that obtained when the test sensitivity was established, readjust the equipment in accordance with Section 8.

10.5 In the event that the equipment presents a signal less than 10% below the standardization level, reexamine, when standardization has been accomplished, all pipe and tubing examined subsequent to the last preceding acceptable standardization.

11. Interpretation of Results

11.1 All indications that are equal to or greater than the reference signals established during standardization as described in Section 9, or as specified in Section 6, shall be considered as representing defects that may be cause for rejection of the pipe or tube.

11.2 If upon examination of the pipe or tube, no rejectable indications are detected, the material shall be considered as having passed the ultrasonic examination, except as noted in 10.5.

12. Keywords

12.1 angle beam; longitudinal welded pipe; longitudinal welded tubing; nondestructive examination; ultrasonic examination

STANDARD PRACTICE FOR MEASURING THICKNESS BY MANUAL ULTRASONIC PULSE-ECHO CONTACT METHOD

SE-797.2

[Identical with ASTM E 797-95 (R2001)]

1. Scope

1.1 This practice provides guidelines for measuring the thickness of materials using the contact pulse-echo method at temperatures not to exceed 200°F (93°C).

1.2 This practice is applicable to any material in which ultrasonic waves will propagate at a constant velocity throughout the part, and from which back reflections can be obtained and resolved.

1.3 The values stated in either inch-pound or SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Examination Systems Without the Use of Electronic Measurement Instruments

E 494 Practice for Measuring Ultrasonic Velocity in Materials

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Document:*

Nondestructive Testing Handbook, 2nd Edition, Vol 7

3. Terminology

3.1 *Definitions* — For definitions of terms used in this practice, refer to Terminology E 1316.

4. Summary of Practices

4.1 Thickness (T), when measured by the pulse-echo ultrasonic method, is a product of the velocity of sound in the material and one half the transit time (round trip) through the material.

$$T = \frac{Vt}{2}$$

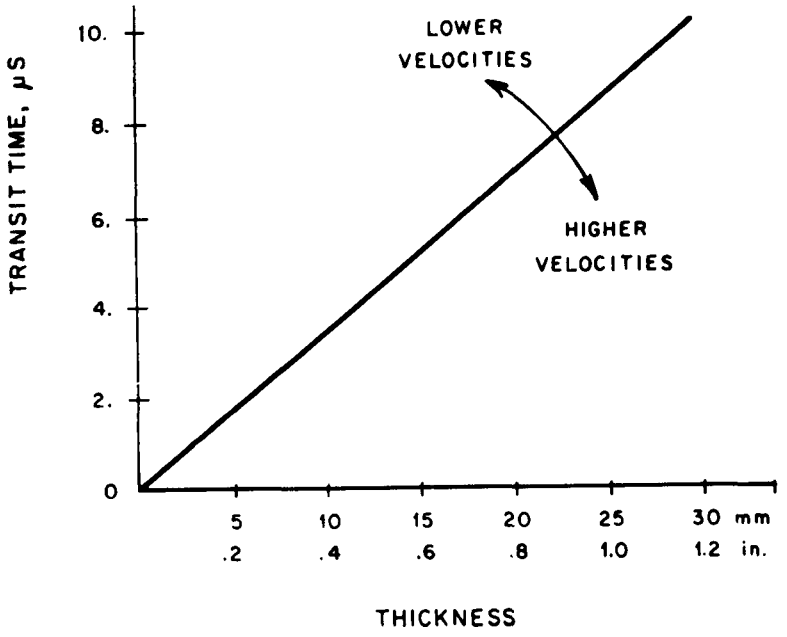
where:

T = thickness,
V = velocity, and
t = transit time.

4.2 The pulse-echo ultrasonic instrument measures the transit time of the ultrasonic pulse through the part.

4.3 The velocity in the material being examined is a function of the physical properties of the material. It is usually assumed to be a constant for a given class of materials. Its approximate value can be obtained from Table X3.1 in Practice E 494 or from the *Nondestructive Testing Handbook*, or it can be determined empirically.

4.4 One or more reference blocks are required having known velocity, or of the same material to be examined, and having thicknesses accurately measured and in the range of thicknesses to be measured. It is generally desirable that the thicknesses be "round numbers" rather than miscellaneous odd values. One block should have a thickness value near the maximum of the range of interest and another block near the minimum thickness.



NOTE – Slope of velocity conversion line is approximately that of steel.

FIG. 1 TRANSIT TIME/THICKNESS RELATIONSHIP

4.5 The display element [CRT (cathode ray tube), meter, or digital display] of the instrument must be adjusted to present convenient values of thickness dependent on the range being used. The control for this function may have different names on different instruments, including *range*, *sweep*, *material standardize*, or *velocity*.

4.6 The timing circuits in different instruments use various conversion schemes. A common method is the so-called time/analog conversion in which the time measured by the instrument is converted into a proportional dc voltage which is then applied to the readout device. Another technique uses a very high-frequency oscillator that is modulated or gated by the appropriate echo indications, the output being used either directly to suitable digital readouts or converted to a voltage for other presentation. A relationship of transit time versus thickness is shown graphically in Fig. 1.

5. Significance and Use

5.1 The techniques described provide indirect measurement of thickness of sections of materials not exceeding temperatures of 200°F (93°C). Measurements are made from one side of the object, without requiring access to the rear surface.

5.2 Ultrasonic thickness measurements are used extensively on basic shapes and products of many materials, on precision machined parts, and to determine wall thinning in process equipment caused by corrosion and erosion.

5.3 Recommendations for determining the capabilities and limitations of ultrasonic thickness gages for specific applications can be found in the cited references.

6. Apparatus

6.1 *Instruments* — Thickness-measurement instruments are divided into three groups: *(1)* Flaw detectors with CRT readout, *(2)* Flaw detectors with CRT and direct thickness readout, and *(3)* Direct thickness readout.

6.1.1 Flaw detectors with CRT readouts display time/amplitude information in an A-scan presentation. Thickness determinations are made by reading the distance between the zero-corrected initial pulse and first-returned echo (back reflection), or between multiple-back reflection echoes, on a standardized base line of a CRT. The base line of the CRT should be adjusted for the desired thickness increments.

6.1.2 Flaw detectors with numeric readout are a combination pulse ultrasound flaw detection instrument with a CRT and additional circuitry that provides digital thickness information. The material thickness can be electronically measured and presented on a digital readout. The CRT provides a check on the validity of the electronic measurement by revealing measurement variables, such

as internal discontinuities, or echo-strength variations, which might result in inaccurate readings.

6.1.3 Thickness readout instruments are modified versions of the pulse-echo instrument. The elapsed time between the initial pulse and the first echo or between multiple echoes is converted into a meter or digital readout. The instruments are designed for measurement and direct numerical readout of specific ranges of thickness and materials.

6.2 *Search Units* — Most pulse-echo type search units (straight-beam contact, delay line, and dual element) are applicable if flaw detector instruments are used. If a thickness readout instrument has the capability to read thin sections, a highly damped, high-frequency search unit is generally used. High-frequency (10 MHz or higher) delay line search units are generally required for thicknesses less than about 0.6 mm (0.025 in.). Measurements of materials at high temperatures require search units specially designed for the application. When dual element search units are used, their inherent nonlinearity usually requires special corrections for thin sections. (See Fig. 2.) For optimum performance, it is often necessary that the instrument and search units be matched.

6.3 *Standardization Blocks* — The general requirements for appropriate standardization blocks are given in 4.4, 7.1.3, 7.2.2.1, 7.3.2, and 7.4.3. Multi-step blocks that may be useful for these standardization procedures are described in Appendix X1 (Figs. X1.1 and X1.2).

7. Standardization of Apparatus

7.1 *Case I — Direct Contact, Single-Element Search Unit:*

7.1.1 *Conditions* — The display start is synchronized to the initial pulse. All display elements are linear. Full thickness is displayed on CRT.

7.1.2 Under these conditions, we can assume that the velocity conversion line effectively pivots about the origin (Fig. 1). It may be necessary to subtract the wear-plate time, requiring minor use of delay control. It is recommended that standardization blocks providing a minimum of two thicknesses that span the thickness range be used to check the full-range accuracy.

7.1.3 Place the search unit on a standardization block of known thickness with suitable couplant and adjust the instrument controls (material standardization, range, sweep, or velocity) until the display presents the appropriate thickness reading.

7.1.4 The readings should then be checked and adjusted on standardization blocks with thickness of lesser value to improve the overall accuracy of the system.

7.2 *Case II — Delay Line Single-Element Search Unit:*

7.2.1 *Conditions* — When using this search unit, it is necessary that the equipment be capable of correcting for the time during which the sound passes through the delay line so that the end of the delay can be made to coincide with zero thickness. This requires a so-called "delay" control in the instrument or automatic electronic sensing of zero thickness.

7.2.2 In most instruments, if the material standardize circuit was previously adjusted for a given material velocity, the delay control should be adjusted until a correct thickness reading is obtained on the instrument. However, if the instrument must be completely standardized with the delay line search unit, the following technique is recommended:

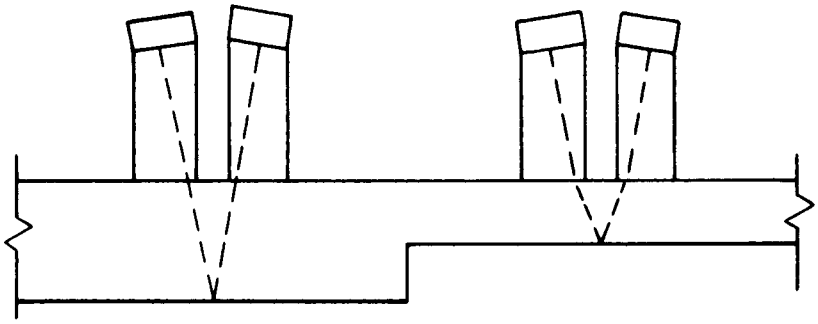
7.2.2.1 Use at least two standardization blocks. One should have a thickness near the maximum of the range to be measured and the other block near the minimum thickness. For convenience, it is desirable that the thickness should be "round numbers" so that the difference between them also has a convenient "round number" value.

7.2.2.2 Place the search unit sequentially on one and then the other block, and obtain both readings. The difference between these two readings should be calculated. If the reading thickness difference is less than the actual thickness difference, place the search unit on the thicker specimen, and adjust the material standardize control to expand the thickness range. If the reading thickness difference is greater than the actual thickness difference, place the search unit on the thicker specimen, and adjust the material standardize control to decrease the thickness range. A certain amount of over correction is usually recommended. Reposition the search unit sequentially on both blocks, and note the reading differences while making additional appropriate corrections. When the reading thickness differential equals the actual thickness differential, the material thickness range is correctly adjusted. A single adjustment of the delay control should then permit correct readings at both the high and low end of the thickness range.

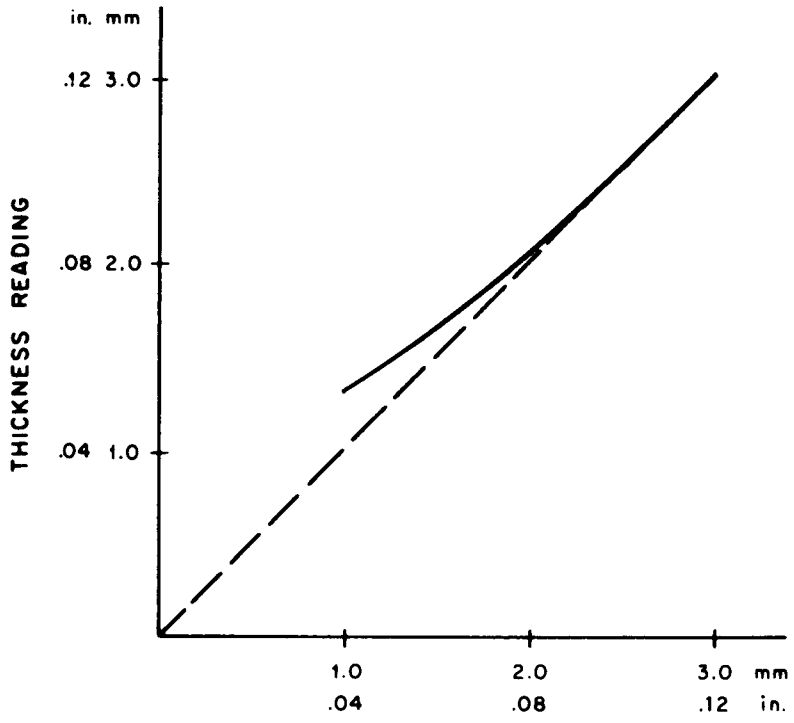
7.2.3 An alternative technique for delay line search units is a variation of that described in 7.2.2. A series of sequential adjustments are made, using the "delay" control to provide correct readings on the thinner standardization block and the "range" control to correct the readings on the thicker block. Moderate over-correction is sometimes useful. When both readings are "correct" the instrument is adjusted properly.

7.3 *Case III — Dual Search Units:*

7.3.1 The method described in 7.2 (Case II) is also suitable for equipment using dual search units in the

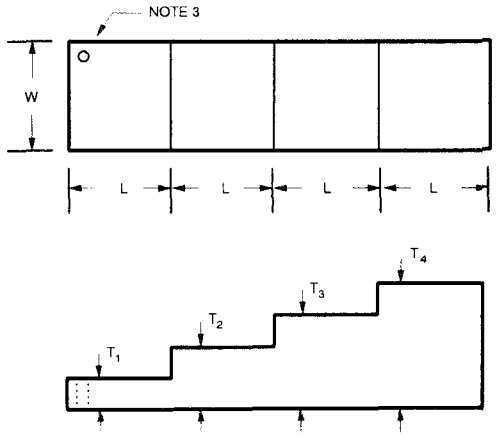


(*a*) Proportional sound path increases with decrease in thickness.



(*b*) Typical reading error values

FIG. 2 DUAL TRANSDUCER NONLINEARITY



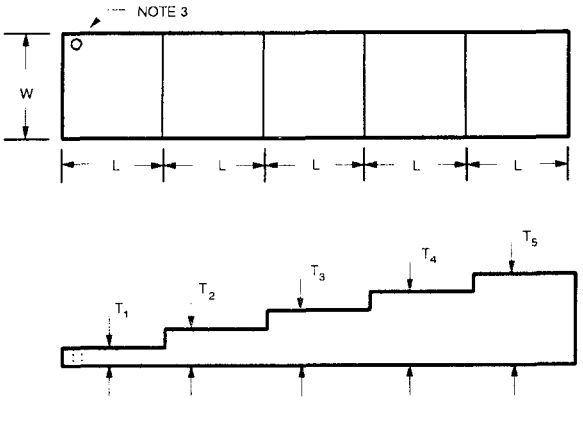
NOT TO SCALE

TABLE OF DIMENSIONS

	U.S. Customary Block, in.		Metric Block 4A, mm		Metric Block 4B, mm	
Legend	Dimension	Tolerance	Dimension	Tolerance	Dimension	Tolerance
T_1	0.250	0.001	6.25	0.02	5.00	0.02
T_2	0.500	0.001	12.50	0.02	10.00	0.02
T_3	0.750	0.001	18.75	0.02	15.00	0.02
T_4	1.000	0.001	25.00	0.02	20.00	0.02
L	0.75	0.02	20.0	0.5	20.0	0.5
W	0.75	0.05	20.0	1.0	20.0	1.0

NOTE 1—Material to be as specified.
NOTE 2—Surface finish: "T" faces Ra 32 μin. (0.8 μm) max. Other surfaces Ra 63 μin. (1.6 μm) max.
NOTE 3—Location for optional 1/16 in. (1.5 mm) diameter through hole used for block support during plating; center 1/16 in. (1.5 mm) from block edges.
NOTE 4—All "T" dimensions to be after any required plating or anodizing.
NOTE 5—In order to prevent sharp edges, minimize plating buildup, or remove in-service nicks and burrs, block edges may be smoothed by beveling or rounding, provided that the corner treatment does not reduce the edge dimension by more than 0.020 in. (0.5 mm).

FIG. X1.1 TYPICAL FOUR-STEP THICKNESS STANDARDIZATION BLOCKS



NOT TO SCALE

TABLE OF DIMENSIONS

	U.S. Customary Block, in.		Metric Block 5A, mm		Metric Block 5B, mm	
Legend	Dimension	Tolerance	Dimension	Tolerance	Dimension	Tolerance
T_1	0.100	0.001	2.50	0.02	2.00	0.02
T_2	0.200	0.001	5.00	0.02	4.00	0.02
T_3	0.300	0.001	7.50	0.02	6.00	0.02
T_4	0.400	0.001	10.00	0.02	8.00	0.02
T_5	0.500	0.001	12.50	0.02	10.00	0.02
L	0.75	0.02	20.0	0.5	20.00	0.5
W	0.75	0.05	20.0	1.0	20.00	1.0

NOTE 1—Material to be as specified.
NOTE 2—Surface finish: "T" faces Ra 32 μin. (0.8 μm) max. Other surfaces Ra 63 μin. (1.6 μm) max.
NOTE 3—Location for optional 1/16 in. (1.5 mm) diameter through hole used for block support during plating; center 1/16 in. (1.5 mm) from block edges.
NOTE 4—All "T" dimensions to be after any required plating or anodizing.
NOTE 5—In order to prevent sharp edges, minimize plating buildup, or remove in-service nicks and burrs, block edges may be smoothed by beveling or rounding, provided that the corner treatment does not reduce the edge dimension by more than 0.020 in. (0.5 mm).

FIG. X1.2 TYPICAL FIVE-STEP THICKNESS STANDARDIZATION BLOCKS

thicker ranges, above 3 mm (0.125 in.). However, below those values there is an inherent error due to the Vee path that the sound beam travels. The transit time is no longer linearly proportional to thickness, and the condition deteriorates toward the low thickness end of the range. The variation is also shown schematically in Fig. 2(a). Typical error values are shown in Fig. 2(b).

7.3.2 If measurements are to be made over a very limited range near the thin end of the scale, it is possible to standardize the instrument with the technique in Case II using appropriate thin standardization blocks. This will produce a correction curve that is approximately correct over that limited range. Note that it will be substantially in error at thicker measurements.

7.3.3 If a wide range of thicknesses is to be measured, it may be more suitable to standardize as in Case II using standardization blocks at the high end of the range and perhaps halfway toward the low end. Following this, empirical corrections can be established for the very thin end of the range.

7.3.4 For a direct-reading panel-type meter display, it is convenient to build these corrections into the display as a nonlinear function.

7.4 *Case IV — Thick Sections:*

7.4.1 *Conditions* — For use when a high degree of accuracy is required for thick sections.

7.4.2 Direct contact search unit and initial pulse synchronization are used. The display start is delayed as described in 7.4.4. All display elements should be linear. Incremental thickness is displayed on the CRT.

7.4.3 Basic standardization of the sweep will be made as described in Case I. The standardization block chosen for this standardization should have a thickness that will permit standardizing the full-sweep distance to adequate accuracy, that is, about 10 mm (0.4 in.) or 25 mm (1.0 in.) full scale.

7.4.4 After basic standardization, the sweep must be delayed. For instance, if the nominal part thickness is expected to be from 50 to 60 mm (2.0 to 2.4 in.), and the basic standardization block is 10 mm (0.4 in.), and the incremental thickness displayed will also be from 50 to 60 mm (2.0 to 2.4 in.), the following steps are required. Adjust the delay control so that the fifth back echo of the basic standardization block, equivalent to 50 mm (2.0 in.), is aligned with the 0 reference on the CRT. The sixth back echo should then occur at the right edge of the standardized sweep.

7.4.5 This standardization can be checked on a known block of the approximate total thickness.

7.4.6 The reading obtained on the unknown specimen must be added to the value delayed off screen. For example, if the reading is 4 mm (0.16 in.), the total thickness will be 54 mm (2.16 in.).

8. Technical Hazards

8.1 Dual search units may also be used effectively with rough surface conditions. In this case, only the first returned echo, such as from the bottom of a pit, is used in the measurement. Generally, a localized scanning search is made to detect the minimum remaining wall.

8.2 *Material Properties* — The instrument should be standardized on a material having the same acoustic velocity and attenuation as the material to be measured. Where possible, standardization should be confirmed by direct dimensional measurement of the material to be examined.

8.3 *Scanning* — The maximum speed of scanning should be stated in the procedure. Material conditions, type of equipment, and operator capabilities may require slower scanning.

8.4 *Geometry:*

8.4.1 Highest accuracy can be obtained from materials with parallel or concentric surfaces. In many cases, it is possible to obtain measurements from materials with nonparallel surfaces. However, the accuracy of the reading may be limited and the reading obtained is generally that of the thinnest portion of the section being interrogated by the sound beam at a given instant.

8.4.2 Relatively small-diameter curves often require special techniques and equipment. When small diameters are to be measured, special procedures including additional specimens may be required to ensure accuracy of setup and readout.

8.5 High-temperature materials, up to about 540°C (1000°F), can be measured with specially designed instruments with high-temperature compensation, search unit assemblies, and couplants. Normalization of apparent thickness readings for elevated temperatures is required. A rule of thumb often used is as follows: The apparent thickness reading obtained from steel walls having elevated temperatures is high (too thick) by a factor of about 1% per 55°C (100°F). Thus, if the instrument was standardized on a piece of similar material at 20°C (68°F), and if the reading was obtained with a surface temperature of 460°C (860°F), the apparent reading should be reduced by 8%. This correction is an average one for many types of steel. Other corrections would have to be determined empirically for other materials.

8.6 *Instrument* — Time-base linearity is required so that a change in the thickness of material will produce a corresponding change of indicated thickness. If a CRT is used as a readout, its horizontal linearity can be checked by using Practice E 317.

8.7 *Back Reflection Wavetrain* — Direct-thickness readout instruments read the thickness at the first half cycle of the wavetrain that exceeds a set amplitude and a fixed time. If the amplitude of the back reflection from the measured material is different from the amplitude of the back reflection from the standardization blocks, the thickness readout may read to a different half cycle in the wavetrain, thereby producing an error. This may be reduced by:

8.7.1 Using standardization blocks having attenuation characteristics equal to those in the measured material or adjusting back reflection amplitude to be equal for both the standardizing blocks and measured material.

8.7.2 Using an instrument with automatic gain control to produce a constant amplitude back reflection.

8.8 *Readouts* — CRT displays are recommended where reflecting surfaces are rough, pitted, or corroded.

8.8.1 Direct-thickness readout, without CRT, presents hazards of misadjustment and misreading under certain test conditions, especially thin sections, rough corroded surfaces, and rapidly changing thickness ranges.

8.9 *Standardization Standards* — Greater accuracy can be obtained when the equipment is standardized on areas of known thickness of the material to be measured.

8.10 Variations in echo signal strength may produce an error equivalent to one or more half-cycles of the RF frequency, dependent on instrumentation characteristics.

9. Procedure Requirements

9.1 In developing the detailed procedure, the following items should be considered:

9.1.1 Instrument manufacturer's operating instructions.

9.1.2 Scope of materials/objects to be measured.

9.1.3 Applicability, accuracy requirements.

9.1.4 Definitions.

9.1.5 Requirements.

9.1.5.1 Personnel.

9.1.5.2 Equipment.

9.1.5.3 Procedure qualification.

9.1.6 Procedure.

9.1.6.1 Measurement conditions.

9.1.6.2 Surface preparation and couplant.

9.1.6.3 Standardization and allowable tolerances.

9.1.6.4 Scanning parameters.

9.1.7 Report.

9.1.7.1 Procedure used.

9.1.7.2 Standardization record.

9.1.7.3 Measurement record.

10. Report

10.1 Record the following information at the time of the measurements and include it in the report:

10.1.1 Examination procedure.

10.1.1.1 Type of instrument.

10.1.1.2 Standardization blocks, size and material type.

10.1.1.3 Size, frequency, and type of search unit.

10.1.1.4 Scanning method.

10.1.2 Results.

10.1.2.1 Maximum and minimum thickness measurements.

10.1.2.2 Location of measurements.

10.1.3 Personnel data, certification level.

11. Keywords

11.1 contact examination; nondestructive testing; pulse-echo; thickness measurement; ultrasonics

ARTICLE 24
LIQUID PENETRANT STANDARDS

STANDARD TEST METHOD FOR SULFUR IN PETROLEUM PRODUCTS (GENERAL BOMB METHOD)

SD-129

(Identical with ASTM D 129-00)
(This specification is available in SI Units only.)

1. Scope

1.1 This test method covers the determination of sulfur in petroleum products, including lubricating oils containing additives, additive concentrates, and lubricating greases that cannot be burned completely in a wick lamp. The test method is applicable to any petroleum product sufficiently low in volatility that it can be weighed accurately in an open sample boat and containing at least 0.1% sulfur.

NOTE 1 — This test method is not applicable to samples containing elements that give residues, other than barium sulfate, which are insoluble in dilute hydrochloric acid and would interfere in the precipitation step. These interfering elements include iron, aluminum, calcium, silicon, and lead which are sometimes present in greases, lube oil additives, or additive oils. Other acid insoluble materials that interfere are silica, molybdenum disulfide, asbestos, mica, etc. The test method is not applicable to used oils containing wear metals, and lead or silicates from contamination. Samples that are excluded can be analyzed by Test Method D 1552.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. See 3.2 for specific precautionary directions incorporated in the test method.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water

D 1552 Test Method for Sulfur in Petroleum Products (High-Temperature Method)

D 6299 Practice for Applying Statistical Quality Assurance Techniques to Evaluate Analytical Measurement System Performance

E 144 Practice for Safe Use of Oxygen Combustion Bombs

3. Summary of Test Method

3.1 The sample is oxidized by combustion in a bomb containing oxygen under pressure. The sulfur, as sulfate in the bomb washings, is determined gravimetrically as barium sulfate.

3.2 Warning — *Strict adherence to all of the provisions prescribed hereafter ensures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least 13 mm thick,*

or equivalent protection be provided against unforseeable contingencies.

4. Apparatus and Materials

4.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test and that quantitative recovery of the liquids from the bomb may be achieved readily. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and lead-wire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the sulfur content of the liquid in the bomb.

4.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside, and weighing 10 to 11 g.

4.3 *Firing Wire,* platinum, No. 26 B & S gage, 0.41 mm (16 thou), 27 SWG, or equivalent. (**Warning** — The switch in the ignition circuit shall be of a type which remains open, except when held in closed position by the operator.)

4.4 *Ignition Circuit,* capable of supplying sufficient current to ignite the cotton wicking or nylon thread without melting the wire. The current shall be drawn from a step-down transformer or from a suitable battery.

4.5 *Cotton Wicking or Nylon Sewing Thread,* white.

5. Reagents and Materials

5.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5.2 *Purity of Water* — Unless otherwise indicated, references to water shall mean water as defined by Type II or III of Specification D 1193.

5.3 *Barium Chloride Solution* (85 g/litre) — Dissolve 100 g of barium chloride dihydrate (BaCl2 • 2H2O) in distilled water and dilute to 1 liter.

5.4 *Bromine Water (saturated).*

5.5 *Hydrochloric Acid (sp gr 1.19)* — Concentrated hydrochloric acid (HCl).

5.6 *Oxygen,* free of combustible material and sulfur compounds, available at a pressure of 41 kgf/cm^2 (40 atm).

5.7 *Sodium Carbonate Solution* (50 g/litre) — Dissolve 135 g of sodium carbonate decahydrate ($Na_2CO_3 \cdot 10H_2O$) or its equivalent weight in distilled water and dilute to 1 litre.

5.8 *White Oil, USP, or Liquid Paraffin,* BP, *or equivalent.*

5.9 *Quality Control (QC) Samples,* preferably are portions of one or more liquid petroleum materials that are stable and representative of the samples of interest. These QC samples can be used to check the validity of the testing process as described in Section 11.

6. Procedure

6.1 *Preparation of Bomb and Sample* — Cut a piece of firing wire 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Insert between two loops of the coil a wisp of cotton or nylon thread of such length that one end will extend into the sample cup. Place about 5 mL of Na_2CO_3 solution in the bomb (Note 2) and rotate the bomb in such a manner that the interior surface is moistened by the solution. Introduce into the sample cup the quantities of sample and white oil (Note 3 and Note 4) specified in the following table, weighing the sample to the nearest 0.2 mg (when white oil is used, stir the mixture with a short length of quartz rod and allow the rod to remain in the sample cup during the combustion).

NOTE 2 — After repeated use of the bomb for sulfur determinations, a film may be noticed on the inner surface. This dullness can be removed by periodic polishing of the bomb. A satisfactory method for doing this is to rotate the bomb in a lathe at about 300 rpm and polish the inside surface with emery polishing papers Grit No. 2/0, or equivalent paper, coated with a light machine oil to prevent cutting, and then with a paste of grit-free chromic oxide and water. This procedure will remove all but very deep pits and put a high polish on the surface. Before the bomb is used it shall be washed with soap and water to remove oil or paste left from the polishing operation.

6.1.1 Warning — Do not use more than 1.0 g total of sample and white oil or other low sulfur combustible material or more than 0.8 g if the IP 12 bomb is used.

Sulfur Content, %	Weight of Sample, g	Weight of White Oil, g
5 or under	0.6 to 0.8	0.0
Over 5	0.3 to 0.4	0.3 to 0.4

NOTE 3 — Use of sample weights containing over 20 mg of chlorine

may cause corrosion of the bomb. To avoid this, it is recommended that for samples containing over 2% chlorine, the sample weight be based on the chlorine content as given in the following table:

Chlorine Content, %	Weight of Sample, g	Weight of White Oil, g
2 to 5	0.4	0.4
Over 5 to 10	0.2	0.6
Over 10 to 20	0.1	0.7
Over 20 to 50	0.05	0.7

NOTE 4 — If the sample is not readily miscible with white oil, some other low sulfur combustible diluent may be substituted. However, the combined weight of sample and nonvolatile diluent shall not exceed 1.0 g or more than 0.8 g if the IP 12 bomb is used.

6.2 *Addition of Oxygen* — Place the sample cup in position and arrange the cotton wisp or nylon thread so that the end dips into the sample. Assemble the bomb and tighten the cover securely. (**Warning** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.) Admit oxygen slowly (to avoid blowing the oil from the cup) until a pressure is reached as indicated in the following table:

Capacity of Bomb, ml	Minimum Gage Pressure,[A] kgf/cm^2 (atm)	Maximum Gage Pressure,[A] kgf/cm^2 (atm)
300 to 350	39 (38)	41 (40)
350 to 400	36 (35)	38 (37)
400 to 450	31 (30)	33 (32)
450 to 500	28 (27)	30 (29)

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures represent a safety requirement.

6.3 *Combustion* — Immerse the bomb in a cold distilled-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. (**Warning** — Do not go near the bomb until at least 20 s after firing.) Remove the bomb from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination and thoroughly clean the bomb before again putting it in use (Note 2).

6.4 *Collection of Sulfur Solution* — Rinse the interior of the bomb, the oil cup, and the inner surface of the bomb cover with a fine jet of water, and collect the washings in a 600-mL beaker having a mark to indicate 75 mL. Remove any precipitate in the bomb by means of a rubber policeman. Wash the base of the terminals until the washings are neutral to the indicator methyl red. Add 10 mL of saturated bromine water to the washings in the beaker. (The volume of the washings is normally in excess of 300 mL.) Place the sample cup in a 50-mL beaker. Add 5 mL of saturated bromine water, 2 mL of HCl, and enough water just to cover the cup. Heat the contents of the beaker to just below its boiling point for 3 or 4 min and add to the beaker containing the bomb washings. Wash the sample cup and the 50-mL beaker thoroughly with water. Remove any precipitate in the cup by means of a rubber policeman. Add the washings from the cup and the 50-mL beaker, and the precipitate, if any, to the bomb washings in the 600-mL beaker. Do not filter any of the washings, since filtering would remove any sulfur present as insoluble material.

6.5 *Determination of Sulfur* — Evaporate the combined washings to 200 mL on a hot plate or other source of heat. Adjust the heat to maintain slow boiling of the solution and add 10 mL of the $BaCl_2$ solution, either in a fine stream or dropwise. Stir the solution during the addition and for 2 min thereafter. Cover the beaker with a fluted watch glass and continue boiling slowly until the solution has evaporated to a volume approximately 75 mL as indicated by a mark on the beaker. Remove the beaker from the hot plate (or other source of heat) and allow it to cool for 1 hr before filtering. Filter the supernatant liquid through an ashless, quantitative filter paper (Note 5). Wash the precipitate with water, first by decantation and then on the filter, until free from chloride. Transfer the paper and precipitate to a weighed crucible and dry (Note 6) at a low heat until the moisture has evaporated. Char the paper completely without igniting it, and finally ignite at a bright red heat until the residue is white in color. After ignition is complete, allow the crucible to cool at room temperature, and weigh.

NOTE 5 — A weighed porcelain filter crucible (Selas type) of 5 to 9-μm porosity may be used in place of the filter paper. In this case the precipitate is washed free of chloride and then dried to constant weight at 500 ±25°C.

NOTE 6 — A satisfactory means of drying, charring, and igniting the paper and precipitate is to place the crucible containing the wet filter paper in a cold electric muffle furnace and to turn on the current. Drying, charring, and ignition usually will occur at the desired rate.

6.6 *Blank* — Make a blank determination whenever new reagents, white oil, or other low-sulfur combustible material are used. When running a blank on white oil, use 0.3 to 0.4 g and follow the normal procedure.

7. Calculation

7.1 Calculate the sulfur content of the sample as follows:

$$\text{Sulfur, weight percent} = (P - B)13.73/W \qquad (1)$$

where:

P = grams of $BaSO_4$ obtained from sample,

B = grams of $BaSO_4$ obtained from blank, and
W = grams of sample used.

8. Report

8.1 Report the results of the test to the nearest 0.01%.

9. Precision and Bias

9.1 The precision of this test is not known to have been obtained in accordance with currently accepted guidelines (for example in Research Report D02-1007).

9.1.1 *Repeatability* — The difference between two test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material, would in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

9.1.2 *Reproducibility* — The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in twenty:

Sulfur, Weight %	Repeatability	Reproducibility
0.1 to 0.5	0.04	0.05
0.5 to 1.0	0.06	0.09
1.0 to 1.5	0.08	0.15
1.5 to 2.0	0.12	0.25
2.0 to 5.0	0.18	0.27

NOTE 7 — The precision shown in the above table does not apply to samples containing over 2% chlorine because an added restriction on the amount of sample which can be ignited is imposed.

NOTE 8 — This test method has been cooperatively tested only in the range of 0.1 to 5.0% sulfur.

NOTE 9 — The following information on the precision of this method has been developed by the Institute of Petroleum (London):

(a) Results of duplicate tests should not differ by more than the following amounts:

Repeatability	Reproducibility
$0.016\ x + 0.06$	$0.037\ x + 0.13$

where x is the mean of duplicate test results.

(b) These precision values were obtained in 1960 by statistical examination of interlaboratory test results. No limits have been established for additive concentrates.

9.2 *Bias* — Results obtained in one laboratory by Test Method D 129 on NIST Standard Reference Material Nos. 1620A, 1621C, and 1662B were found to be 0.05 mass % higher than the accepted reference values.

10. Quality Control

10.1 Confirm the performance of the instrument or the test procedure by analyzing a QC sample (see 6.9).

10.1.1 When QC/Quality Assurance (QA) protocols are already established in the testing facility, these may be used to confirm the reliability of the test result.

10.1.2 When there is no QC/QA protocol established in the testing facility, Appendix X1 can be used as the QC/QA system.

11. Keywords

11.1 bomb; sulfur

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL

X1.1 Confirm the performance of the instrument or the test procedure by analyzing a quality control (QC) sample.

X1.2 Prior to monitoring the measurement process, the user of the test method needs to determine the average value and control limits of the QC sample (see Practice D 6299 and MNL 7).

X1.3 Record the QC results and analyze by control charts or other statistically equivalent techniques to ascertain the statistical control status of the total testing process (see Practice D 6299 and MNL 7). Any out-of-control data should trigger investigation for root cause(s).

X1.4 In the absence of explicit requirements given in the test method, the frequency of QC testing is dependent on the criticality of the quality being measured, the demonstrated stability of the testing process, and customer requirements. Generally, a QC sample is analyzed each testing day with routine samples. The QC frequency should be increased if a large number of samples are routinely analyzed. However, when it is demonstrated that the testing is under statistical control, the QC testing frequency may be reduced. The QC sample precision should be checked against the ASTM method precision to ensure data quality.

X1.5 It is recommended that, if possible, the type of QC sample that is regularly tested be representative of the material routinely analyzed. An ample supply of QC sample material should be available for the intended period of use, and must be homogenous and stable under the anticipated storage conditions. See Practice D 6299 and MNL 7 for further guidance on QC and control charting techniques.

STANDARD TEST METHOD FOR SULFATE ION IN WATER

SD-516

[Identical with ASTM D 516-90 (R1995)$^{\epsilon 1}$]

1. Scope

1.1 This turbidimetric test method covers the determination of sulfate in water in the range from 1 to 40 mg/L of sulfate ion (SO_4^{--}).

1.2 This test method was used successfully with drinking, ground, and surface waters. It is the user's responsibility to ensure the validity of this test method for waters of untested matrices.

1.3 Former gravimetric and volumetric test methods have been discontinued. Refer to Appendix X1 for historical information.

1.4 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1066 Practice for Sampling Steam

D 1129 Terminology Relating to Water

D 1192 Specification for Equipment for Sampling Water and Steam in Closed Conduits

D 1193 Specification for Reagent Water

D 2777 Practice for Determination of Precision and Bias of Applicable Methods of Committee D-19 on Water

D 3370 Practices for Sampling Water from Closed Conduits

E 60 Practice for Photometric and Spectrophotometric Methods for the Chemical Analysis of Metals

E 275 Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near Infrared Spectrophotometers

3. Terminology

3.1 *Definitions* — For definitions of terms used in this test method, refer to Terminology D 1129.

4. Summary of Test Method

4.1 Sulfate ion is converted to a barium sulfate suspension under controlled conditions. A solution containing glycerin and sodium chloride is added to stabilize the suspension and minimize interferences. The resulting turbidity is determined by a nephelometer, spectrophotometer, or photoelectric colorimeter and compared to a curve prepared from standard sulfate solutions.

5. Significance and Use

5.1 The determination of sulfate is important because it has been reported that when this ion is present in excess of about 250 mg/L in drinking water, it causes a cathartic action (especially in children) in the presence of sodium and magnesium, and gives a bad taste to the water.

6. Interferences

6.1 Insoluble suspended matter in the sample must be removed. Dark colors that cannot be compensated for in the procedure interfere with the measurement of suspended barium sulfate ($BaSO_4$).

6.2 Polyphosphates as low as 1 mg/L will inhibit barium sulfate precipitation causing a negative interference. Phosphonates present in low concentrations,

depending on the type of phosphonate, will also cause a negative interference. Silica in excess of 500 mg/L may precipitate along with the barium sulfate causing a positive interference. Chloride in excess of 5000 mg/L will cause a negative interference. Aluminum, polymers, and large quantities of organic material present in the test sample may cause the barium sulfate to precipitate nonuniformly. In the presence of organic matter certain bacteria may reduce sulfate to sulfide. To minimize the action of sulfate reducing bacteria, samples should be refrigerated at 4°C when the presence of such bacteria is suspected.

6.3 Although other ions normally found in water do not appear to interfere, the formation of the barium sulfate suspension is very critical. Determinations that are in doubt may be checked by a gravimetric method in some cases, or by the procedure suggested in Note 2.

7. Apparatus

7.1 *Photometer* — One of the following, which are given in order of preference.

7.1.1 Nephelometer or turbidimeter;

7.1.2 Spectrophotometer for use at 420 nm with light path of 4 to 5 cm;

7.1.3 Filter photometer with a violet filter having a maximum near 420 nm and a light path of 4 to 5 cm.

7.2 *Stopwatch,* if the magnetic stirrer is not equipped with an accurate timer.

7.3 *Measuring Spoon,* capacity 0.2 to 0.3 mL.

7.4 Filter photometers and photometric practices prescribed in this test method shall conform to Practice E 60; spectrophotometer practices shall conform to Practice E 275.

8. Reagents

8.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

8.2 *Purity of Water* — Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Specification D 1193, Type III.

8.3 *Barium Chloride* — Crystals of barium chloride ($BaCl_2 \cdot 2H_2O$) screened to 20 to 30 mesh. To prepare in the laboratory, spread crystals over a large watch glass, desiccate for 24 h, screen to remove any crystals that are not 20 to 30 mesh, and store in a clean, dry jar.

8.4 *Conditioning Reagent* — Place 30 mL of concentrated hydrochloric acid (HCl, sp gr 1.19), 300 mL reagent water, 100 mL 95% ethanol or isopropanol and 75 g sodium chloride (NaCl) in a container. Add 50 mL glycerol and mix.

8.5 *Sulfate Solution, Standard* (1 mL = 0.100 mg SO_4^{--}) — Dissolve 0.1479 g of anhydrous sodium sulfate (Na_2SO_4) in water, and dilute with water to 1 L in a volumetric flask.

9. Sampling

9.1 Collect the sample in accordance with Practice D 1066, Specification D 1192, and Practices D 3370, as applicable.

10. Calibration

10.1 Follow the procedure given in Section 11, using appropriate amounts of the standard sulfate solution prepared in accordance with 8.5 and prepare a calibration curve showing sulfate ion content in milligrams per litre plotted against the corresponding photometer readings (Note 1). Prepare standards by diluting with water 0.0, 2.0, 5.0, 10.0, 15.0, 20.0, 30.0, and 40.0 mL of standard sulfate solution to 100-mL volumes in volumetric flasks. These solutions will have sulfate ion concentrations of 0.0, 2.0, 5.0, 10.0, 15.0, 20.0, 30.0, and 40.0 mg/L (ppm), respectively.

NOTE 1 — A separate calibration curve must be prepared for each photometer and a new curve must be prepared if it is necessary to change the cell, lamp, or filter, or if any other alterations of instrument or reagents are made. Check the curve with each series of tests by running two or more solutions of known sulfate concentrations.

11. Procedure

11.1 Filter the sample if it is turbid, and adjust the temperature to between 15 and 30°C.

11.2 Pipet into a 250-mL beaker 100 mL or less of the clear sample containing between 0.5 and 4 mg of sulfate ion (Note 2). Dilute to 100 mL with water if required, and add 5.0 mL of conditioning reagent (Note 1).

NOTE 2 — The solubility of $BaSO_4$ is such that difficulty may be experienced in the determination of sulfate concentrations below about 5 mg/L (ppm). This can be overcome by concentrating the sample or by adding 5 mL of standard sulfate solution (1 mL = 0.100 mg SO_4^{--})

TABLE 1
OVERALL (S_T) AND SINGLE-OPERATOR (S_O) STANDARD DEVIATIONS AGAINST MEAN CONCENTRATION FOR INTERLABORATORY RECOVERY OF SULFATE FROM REAGENT WATER[A]

Mean Concentration ($\bar{X}$), mg/L	Standard Deviation, mg/L	
	S_T	S_O
6.6	0.5	0.1
20.4	1.0	0.4
63.7	2.5	1.3

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

to the sample before diluting to 100 mL. This will add 0.5 mg SO_4 to the sample, which must be subtracted from the final result.

11.3 Mix in the stirring apparatus.

11.4 While the solution is being stirred, add a measured spoonful of $BaCl_2$ crystals (0.3 g) and begin timing immediately.

11.5 Stir exactly 1.0 min at constant speed.

NOTE 3 — The stirring should be at a constant rate in all determinations. The use of a magnetic stirrer has been found satisfactory for this purpose.

11.6 Immediately after the stirring period has ended, pour solution into the cell and measure the turbidity at 30-s intervals for 4 min. Record the maximum reading obtained in the 4-min period.

11.7 If the sample contains color or turbidity, run a sample blank using the procedure 11.2 through 11.6 without the addition of the barium chloride.

11.8 If interferences are suspected, dilute the sample with an equal volume of water, and determine the sulfate concentration again. If the value so determined is one half that in the undiluted sample, interferences may be assumed to be absent.

12. Calculation

12.1 Convert the photometer readings obtained with the sample to milligrams per litre sulfate ion (SO_4^{--}) by use of the calibration curve described in Section 10.

13. Precision and Bias

13.1 The precision and bias data presented in this test method meet the requirements of Practice D 2777-86.

13.2 The overall and single-operator precision of the test method, within its designated range, varies with the quantity being tested according to Table 1 for reagent water and Table 2 for drinking, ground, and surface waters.

TABLE 2
OVERALL (S_T) AND SINGLE-OPERATOR (S_O) STANDARD DEVIATIONS AGAINST MEAN CONCENTRATION FOR INTERLABORATORY RECOVERY OF SULFATE FROM DRINKING, GROUND, AND SURFACE WATER[A]

Mean Concentration ($\bar{X}$), mg/L	Standard Deviation, mg/L	
	S_T	S_O
6.9	0.7	0.5
20.2	2.2	1.8
63.3	4.5	1.6

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

TABLE 3
DETERMINATION OF BIAS[A]

	Amount Added, mg/L	Amount Found, mg/L	±Bias	±%Bias	Statistically Significant at 5% Level (at ± 0.05)
Reagent water	20.8	20.4	−0.4	−1.9%	No
	63.9[A]	63.7[A]	−0.2	−0.2%	No
	7.0	6.6	−0.4	−5.3%	No
Drinking, ground and surface water	20.8	20.2	−0.6	−2.7%	No
	63.9[A]	63.3[A]	−0.6	−0.9%	No
	7.0	6.9	−0.1	−1.8%	No

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

13.2.1 Seven laboratories participated in the round robin at three levels in triplicate, making a total of 21 observations at each level for reagent water and for matrix water (drinking, ground, and surface water).

13.3 Recoveries of known amounts of sulfate from reagent water and drinking, ground, and surface waters are as shown in Table 3.

13.3.1 A table for estimating the bias of the test method through its applicable concentration range can be found in Table 4.

13.3.2 These collaborative test data were obtained on reagent grade water and natural waters. For other matrices, these data may not apply.

14. Keywords

14.1 drinking water; ground water; sulfate; surface water; turbidimetric

TABLE 4
MEAN SULFATE RECOVERY AGAINST CONCENTRATION ADDED WITH OVERALL STANDARD DEVIATION SHOWN FOR INTERLABORATORY EXPERIMENTAL RECOVERY OF SULFATE FROM REAGENT WATER AND DRINKING, GROUND, AND SURFACE WATER[A]

Sulfate Added, mg/L	Mean Surface Recovery ($\bar{X}$), mg/L	
	Reagent Water (S_T)	Matrix Water (S_O)
7.0	6.6 (0.5)	6.9 (0.7)
20.8	20.4 (1.0)	20.2 (2.2)
63.9	63.7 (2.5)	63.3 (4.5)

[A] The test method is linear to 40 mg/L. Testing at the 63.9 level was accomplished through dilution as described in 11.2.

APPENDIX

(Nonmandatory Information)

X1. RATIONALE FOR DISCONTINUATION OF METHODS

X1.1 *Gravimetric:*

X1.1.1 This test method was discontinued in 1988. The test method may be found in the *1988 Annual Book of ASTM Standards,* Vol 11.01. The test method was originally issued in 1938.

X1.1.2 This test method covers the determination of sulfate in water and wastewater. Samples containing from 20 to 100 mg/L of sulfate may be analyzed.

X1.1.3 Sulfate is precipitated and weighted as barium sulfate after removal of silica and other insoluble matter.

X1.1.4 This test method was discontinued because there were insufficient laboratories interested in participating in another collaborative study to obtain the necessary precision and bias as required by Practice D 2777.

X1.2 *Volumetric:*

X1.2.1 This test method was discontinued in 1988. The test method may be found in the *1988 Annual Book of ASTM Standards,* Vol 11.01. The test method was originally issued in 1959 as a non-referee method, and made the primary method in the 1980 issue of Test Method D 516.

X1.2.2 This test method covers the determination of sulfate in industrial water. Samples containing from 5 to 1000 mg/L of sulfate may be analyzed.

X1.2.3 Sulfate is titrated in an alcoholic solution under controlled acid conditions with a standard barium chloride solution using thorin as the indicator.

X1.2.4 This test method was discontinued because there were insufficient laboratories interested in participating in another collaborative study to obtain the necessary precision and bias as required by Practice D 2777.

STANDARD TEST METHOD FOR CHLORINE IN NEW AND USED PETROLEUM PRODUCTS (BOMB METHOD)

SD-808

(Identical with ASTM D 808-00)

1. Scope

1.1 This test method covers the determination of chlorine in lubricating oils and greases, including new and used lubricating oils and greases containing additives, and in additive concentrates. Its range of applicability is 0.1 to 50% chlorine. The procedure assumes that compounds containing halogens other than chlorine will not be present.

1.2 The preferred units are mass percent and SI.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products

D 6299 Practice for Applying Statistical Quality Assurance Techniques to Evaluate Analytical Measurement Performance

3. Summary of Test Method

3.1 The sample is oxidized by combustion in a bomb containing oxygen under pressure. (**Warning** — Strict adherence to all of the provisions prescribed hereinafter ensures against explosive rupture of the bomb, or a blowout, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least 13 mm (½ in.) thick, or equivalent protection be provided against unforseeable contingencies.) The chlorine compounds thus liberated are absorbed in a sodium carbonate solution and the amount of chlorine present is determined gravimetrically by precipitation as silver chloride.

4. Significance and Use

4.1 This test method may be used to measure the level of chlorine-containing compounds in petroleum products. This knowledge can be used to predict performance or handling characteristics of the product in question.

5. Apparatus

5.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and lead-wire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the chlorine content of the liquid in the bomb.

5.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside, and weighing 10 to 11 g.

5.3 *Firing Wire,* platinum, No. 26 B & S gage 0.41 (16 thou), 27 SWG or equivalent.

5.4 *Ignition Circuit,* capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

5.4.1 The switch in the ignition circuit shall be of a type that remains open, except when held in closed position by the operator.

5.5 *Nylon Sewing Thread, or Cotton Wicking,* white.

5.6 *Filter Crucible,* fritted-glass, 30-mL capacity, medium porosity.

6. Reagents and Materials

6.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

6.2 *Purity of Water* — Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type II or III of Specification D 1193.

6.3 *Nitric Acid* (1 + 1) — Mix equal volumes of concentrated nitric acid (HNO_3, sp gr 1.42) and water.

6.4 *Oxygen,* free of combustible material and halogen compounds, available at a pressure of 41 kgf/cm^2 (40 atmos). (**Warning** — Oxygen vigorously accelerates combustion.)

6.5 *Silver Nitrate Solution* (50 g $AgNO_3$/L) — Dissolve 50 g of silver nitrate ($AgNO_3$) in water and dilute to 1 L.

6.6 *Sodium Carbonate Solution* (50 g Na_2CO_3/L) — Dissolve 50 g of anhydrous Na_2CO_3, 58.5 g of $Na_2CO_3 \cdot H_2O$, or 135 g of $Na_2CO_3 \cdot 10\ H_2O$ in water and dilute to 1 L.

6.7 *White Oil,* refined.

6.8 *Quality Control (QC) Samples,* preferably are portions of one or more liquid petroleum materials that are stable and representative of the samples of interest. These QC samples can be used to check the validity of the testing process as described in Section 10.

7. Sampling

7.1 Take samples in accordance with the instructions in Practice D 4057.

TABLE 1
QUANTITIES OF SAMPLE AND WHITE OIL

Chlorine Content, %	Weight of Sample, g	Weight of White Oil, g
2 and under	0.8	0.0
Above 2 to 5, incl	0.4	0.4
Above 5 to 10, incl	0.2	0.6
Above 10 to 20, incl	0.1	0.7
Above 20 to 50, incl	0.05	0.7

7.2 Take care that the sample is thoroughly representative of the material to be tested and that the portion of the sample used for the test is thoroughly representative of the whole sample.

8. Procedure

8.1 *Preparation of Bomb and Sample* — Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Insert into the coil a nylon thread, or wisp of cotton, of such length that one end will extend into the sample cup. Place about 5 mL of Na_2CO_3 solution in the bomb and by means of a rubber policeman, wet the interior surface of the bomb, including the head, as thoroughly as possible. Introduce into the sample cup the quantities of sample and white oil (Note 1) (**Warning** — Do not use more than 1 g total of sample and white oil or other chlorine free combustible material.) specified in Table 1 (**Warning** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.), weighing the sample to the nearest 0.2 mg. (When white oil is used, stir the mixture with a short length of quartz rod and allow the rod to remain in the sample cup during the combustion.)

8.1.1 After repeated use of the bomb for chlorine determination, a film may be noticed on the inner surface. This dullness can be removed by periodic polishing of the bomb. A satisfactory method for doing this is to rotate the bomb in a lathe at about 300 rpm and polish the inside with Grit No. 2/0 or equivalent paper coated with a light machine oil to prevent cutting, and then with a paste of grit-free chromic oxide and water. This procedure will remove all but very deep pits and put a high polish on the surface. Before using the bomb wash it with soap and water to remove oil or paste left from the polishing operation. Bombs with porous or pitted surfaces should never be used because of the tendency to retain chlorine from sample to sample.

TABLE 2
GAGE PRESSURE

Capacity of Bomb, mL	Minimum Gage Pressure,[A] kgf/cm² (atm)	Maximum Gage Pressure,[A] kgf/cm² (atm)
300 to 350	39 (38)	41 (40)
350 to 400	36 (35)	38 (37)
400 to 450	31 (30)	33 (32)
450 to 500	28 (27)	30 (29)

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion, and the *maximum pressures represent a safety requirement.*

8.1.2 When the sample is not readily miscible with white oil, some other nonvolatile, chlorine-free combustible diluent may be employed in place of white oil. However, the combined weight of sample and nonvolatile diluent shall not exceed 1 g. Some solid additives are relatively insoluble, but may be satisfactorily burned when covered with a layer of white oil. (**Warning** — Do not use more than 1 g total of sample and white oil or other chlorine-free combustible material.)

NOTE 1 — The practice of running alternately high and low samples in chlorine content shall be avoided whenever possible. It is difficult to rinse the last traces of chlorine from the walls of the bomb and the tendency for residual chlorine to carry over from sample to sample has been observed in a number of laboratories. When a sample high in chlorine has preceded one low in chlorine content, the test on the low-chlorine sample shall be repeated and one or both of the low values thus obtained can be considered suspect if they do not agree within the limits of repeatability of this method.

8.2 *Addition of Oxygen* — Place the sample cup in position and arrange the nylon thread, or wisp of cotton, so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen (**Warning** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.) slowly (to avoid blowing the oil from the cup) until a pressure is reached as indicated in Table 2.

8.3 *Combustion* — Immerse the bomb in a cold water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the bomb from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use (8.1.1).

8.4 *Collection of Chlorine Solution* — Rinse the interior of the bomb, the sample cup, and the inner surface of the bomb cover with a fine jet of water, and collect the washings in a 600-mL beaker. Scrub the interior of the bomb and the inner surface of the bomb cover with a rubber policeman. Wash the base of the terminals until the washings are neutral to the indicator methyl red. (The volume of the washings is normally in excess of 300 mL.) Take special care not to lose any wash water.

8.5 *Determination of Chlorine* — Acidify the solution by adding HNO_3 (1 + 1) drop by drop until acid to methyl red. Add an excess of 2 mL of the HNO_3 solution. Filter through a qualitative paper (if the solution is cloudy, the presence of lead chloride ($PbCl_2$) is indicated and the solution should be brought to a boil before filtering) and collect in a second 600-mL beaker. Heat the solution to about 60°C (140°F) and, while protecting the solution from strong light, add gradually, while stirring, 5 mL of $AgNO_3$ solution. Heat to incipient boiling and retain at this temperature until the supernatant liquid becomes clear. Test to ensure complete precipitation by adding a few drops of the $AgNO_3$ solution. If more precipitation takes place, repeat the above steps which have involved heating, stirring, and addition of $AgNO_3$, as often as necessary, until the additional drops of $AgNO_3$ produce no turbidity in the clear, supernatant liquid. Allow the beaker and contents to stand in a dark place for at least an hour. Filter the precipitate by suction on a weighed fritted-glass filter crucible. Wash the precipitate with water containing 2 mL of HNO_3 (1 + 1)/L. Dry the crucible and precipitate at 110°C for 1 h. Cool in a desiccator, and weigh.

8.6 *Blank* — Make a blank determination with 0.7 to 0.8 g of white oil by following the normal procedure but omitting the sample (Note 2 and Note 9). Repeat this blank whenever new batches of reagents or white oil are used. The blank must not exceed 0.03% chlorine based upon the weight of the white oil.

NOTE 2 — This procedure measures chlorine in the white oil and in the reagents used, as well as that introduced from contamination.

9. Calculation

9.1 Calculate the chlorine content of the sample as follows:

$$\text{Chlorine, mass \%} = [(P - B) \times 24.74]/W \quad (1)$$

where:

P = grams of AgCl obtained from the sample,
B = grams of AgCl obtained from the blank, and
W = grams of sample used.

10. Quality Control

10.1 Confirm the performance of the instrument or the test procedure by analyzing a QC sample (see 6.8).

10.1.1 When QC/Quality Assurance (QA) protocols are already established in the testing facility, these may be used to confirm the reliability of the test result.

10.1.2 When there is no QC/QA protocol established in the testing facility, Appendix X1 can be used as the QC/QA system.

11. Precision and Bias

11.1 The precision of this test method is not known to have been obtained in accordance with currently accepted guidelines (for example., in Committee D-2 Research Report RR:D2-1007, Manual on Determining Precision Data for ASTM Methods on Petroleum Products and Lubricants).

11.2 The precision of this test method as obtained by statistical examination of interlaboratory test results is as follows:

11.2.1 *Repeatability* — The difference between successive test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method exceed the following values only in one case in twenty:

Chlorine, %	Repeatability
0.1 to 1.9	0.07
2.0 to 5.0	0.15
Above 5.0	3% of amount present

11.2.2 *Reproducibility* — The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method exceed the following values only in one case in twenty:

Chlorine, %	Reproducibility
0.1 to 1.9	0.10
2.0 to 5.0	0.30
Above 5.0	5% of amount present

11.3 *Bias:*

11.3.1 Cooperative data indicate that deviations of test results from the true chlorine content are of the same order of magnitude as the reproducibility.

11.3.2 It is not practicable to specify the bias of this test method for measuring chlorine because the responsible subcommittee, after diligent search, was unable to attract volunteers for an interlaboratory study.

12. Keywords

12.1 bomb; chlorine

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL

X1.1 Confirm the performance of the instrument or the test procedure by analyzing a QC sample.

X1.2 Prior to monitoring the measurement process, the user of the method needs to determine the average value and control limits of the QC sample (see Practice D 6299 and MNL 7).

X1.3 Record the QC results and analyze by control charts or other statistically equivalent techniques to ascertain the statistical control status of the total testing process (see Practice D 6299 and MNL 7). Any out-of-control data should trigger investigation for root cause(s).

X1.4 In the absence of explicit requirements given in the test method, the frequency of QC testing is dependent on the criticality of the quality being measured, the demonstrated stability of the testing process, and customer requirements. Generally, a QC sample is analyzed each testing day with routine samples. The QC frequency should be increased if a large number of samples are routinely analyzed. However, when it is demonstrated that the testing is under statistical control, the QC testing frequency may be reduced. The QC sample precision should be checked against the ASTM method precision to ensure data quality.

X1.5 It is recommended that, if possible, the type of QC sample that is regularly tested be representative of the material routinely analyzed. An ample supply of QC sample material should be available for the intended period of use, and must be homogenous and stable under the anticipated storage conditions. See Practice D 6299 and MNL 7 for further guidance on QC and Control Charting techniques.

STANDARD TEST METHOD FOR SULFUR IN PETROLEUM PRODUCTS (HIGH-TEMPERATURE METHOD)

SD-1552

(Identical with ASTM D 1552-00)

1. Scope

1.1 This test method covers three procedures for the determination of total sulfur in petroleum products including lubricating oils containing additives, and in additive concentrates. This test method is applicable to samples boiling above 177°C (350°F) and containing not less than 0.06 mass % sulfur. Two of the three procedures use iodate detection; one employing an induction furnace for pyrolysis, the other a resistance furnace. The third procedure uses IR detection following pyrolysis in a resistance furnace.

1.2 Petroleum coke containing up to 8 mass % sulfur can be analyzed.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water

D 1266 Test Method for Sulfur in Petroleum Products (Lamp Method)

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products

D 6299 Practice for Applying Statistical Quality Assurance Techniques to Evaluate Analytical Measurement System Performance

3. Summary of Test Method

3.1 *Iodate Detection System* — The sample is burned in a stream of oxygen at a sufficiently high temperature to convert about 97% of the sulfur to sulfur dioxide. A standardization factor is employed to obtain accurate results. The combustion products are passed into an absorber containing an acid solution of potassium iodide and starch indicator. A faint blue color is developed in the absorber solution by the addition of standard potassium iodate solution. As combustion proceeds, bleaching the blue color, more iodate is added. The amount of standard iodate consumed during the combustion is a measure of the sulfur content of the sample.

3.2 *IR Detection System* — The sample is weighed into a special ceramic boat which is then placed into a combustion furnace at 1371°C (2500°F) in an oxygen atmosphere. Most sulfur present is combusted to SO_2 which is then measured with an infrared detector after moisture and dust are removed by traps. A microprocessor calculates the mass percent sulfur from the sample weight, the integrated detector signal, and a predetermined calibration factor. Both the sample identification number and mass percent sulfur are then printed out. The calibration factor is determined using standards approximating the material to be analyzed.

4. Significance and Use

4.1 This test method provides a means of monitoring the sulfur level of various petroleum products and additives. This knowledge can be used to predict performance, handling, or processing properties. In some cases the presence of sulfur compounds is beneficial to the product and monitoring the depletion of sulfur can provide useful

information. In other cases the presence of sulfur compounds is detrimental to the processing or use of the product.

5. Interferences

5.1 For the iodate systems, chlorine in concentrations less than 1 mass % does not interfere. The IR system can tolerate somewhat higher concentrations. Nitrogen when present in excess of 0.1 mass % may interfere with the iodate systems; the extent of such interference may be dependent on the type of nitrogen compound as well as the combustion conditions. Nitrogen does not interfere with the IR system. The alkali and alkaline earth metals, as well as zinc, phosphorus, and lead, do not interfere with either system.

6. Apparatus

6.1 *Combustion and Iodate Detection System*

6.1.1 *Furnaces* — Two major types are available, the primary difference being the manner in which the necessary high temperatures are obtained. These two types are as follows:

6.1.1.1 *Induction Type,* which depends upon the high-frequency electrical induction method of heating. This assembly shall be capable of attaining a temperature of at least 1482°C (2700°F) in the sample combustion zone, under the conditions set forth in Section 10 and shall be equipped with an additional induction coil located above the combustion zone, substantially as shown in Fig. 1.

6.1.1.2 The furnace work coil should have a minimum output of 500 W; the minimum input rating of the furnace must be 1000 W. With the correct amount of iron chips, weighed to ±0.05 g, the maximum plate current will be between 350 and 450 mA. **Warning** — This type of furnace is capable of inflicting high-frequency burns and high-voltage shocks. In addition to other precautions, maintain all guards properly. **Warning** — Disconnect the furnace from the power line whenever electrical repairs or adjustments are made.

6.1.1.3 *Resistance Type,* capable of maintaining a temperature of at least 1371°C (2500°F).

6.1.2 *Absorber,* as described in Test Method D 1266.

NOTE 1 — Also suitable for use with either type of furnace is an automatic titrator, specifically designed for iodometry. This combines the functions of absorption and titration to a predetermined end point.

6.1.3 *Buret,* standard 25-mL or automatic types available from the manufacturers of the specific combustion units, are suitable (Note 2).

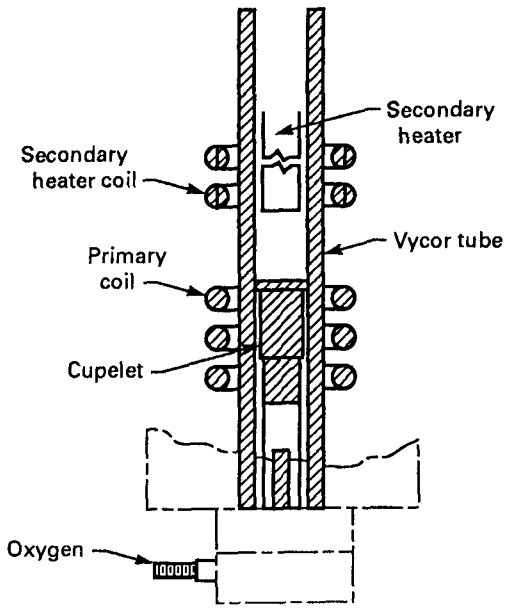


FIG. 1 COMBUSTION TUBE

6.2 *Combustion and IR Detection System,* comprised of automatic balance, oxygen flow controls, drying tubes, combustion furnace, infrared detector and microprocessor. The furnace shall be capable of maintaining a nominal operating temperature of 1350°C (2460°F).

6.3 *Miscellaneous Apparatus* — Specific combustion assemblies require additional equipment such as crucibles, combustion boats, crucible lids, boat pushers, separator disks, combustion tubes, sample inserters, oxygen flow indicator, and oxygen drying trains. The additional equipment required is dependent on the type of furnace used and is available from the manufacturer of the specific combustion unit. To attain the lower sulfur concentration given in Section 1, the ceramics used with the induction furnace assembly shall be ignited in a muffle furnace at 1371°C (2500°F) for at least 4 h before use.

6.4 *Sieve,* 60-mesh (250-mm).

7. Reagents and Materials

7.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2 *Purity of Water* — Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type II or III of Specification D 1193.

7.3 *Alundum* (Al_2O_3) or *Magnesium Oxide* (Com-Aid).

7.4 *Anhydrone (Magnesium Perchlorate).* **Warning** — In addition to other precautions, handle magnesium perchlorate with care. Avoid contacting it with acid and organic materials. Reactions with fuel may be violent.

7.5 *Hydrochloric Acid* (3 + 197) — Dilute 30 mL of concentrated hydrochloric acid (HCl, relative density 1.19) to 2 L with water. **Warning** — Poison. Corrosive. May be fatal if swallowed. Liquid and vapor cause severe burns.

7.6 *Oxygen (Extra Dry)* — The oxygen shall be at least 99.5% pure and show no detectable sulfur by blank determination. **Warning** — Oxygen vigorously accelerates combustion.

7.7 *Phosphorus Pentoxide* (P_2O_5).

7.8 *Potassium Alum (Aluminum Potassium Sulfate).*

7.9 *Potassium Iodate, Standard Solution* (0.06238 *M*, 1 mL = 1 mg S) — Dissolve 2.225 g of potassium iodate (KIO_3) that has been dried at about 180°C to constant weight, in water and dilute to 1 L. Thoroughly mix the solution.

7.10 *Potassium Iodate, Standard Solution* (0.006238 *M*, 1 mL = 0.1 mg S) — Measure exactly 100 mL of KIO_3 solution (0.06238 *M*, 1 mL = 1 mg S) into a 1-L volumetric flask, and dilute to volume with water. Thoroughly mix the solution.

7.11 *Potassium Iodate, Standard Solution* (0.01248 *M*, 1 mL = 0.2 mg S) — Measure exactly 200 mL of KIO_3 solution (0.06238 *M*, 1 mL = 1 mg S) into a 1-L volumetric flask and dilute to volume with water. Thoroughly mix the solution.

7.12 *Ascarite,* 8 to 20 mesh.

7.13 *Special Materials for Induction-Type Furnaces:*

7.13.1 *Tin* (20 to 30-mesh).

7.13.2 *Iron-Chip Accelerator* having a sulfur content of not more than 0.005 mass %.

7.14 *Standard Sample* — Potassium alum [$AlK(SO_4)_2 \cdot 12H_2O$].

7.15 *Starch-Iodide Solution* — Make a paste by adding 9 g of soluble starch to 15 mL of water. Add this mixture, with stirring, to 500 mL of boiling water. Cool the mixture, add 15 g of potassium iodide (KI), and dilute to 1 L with water.

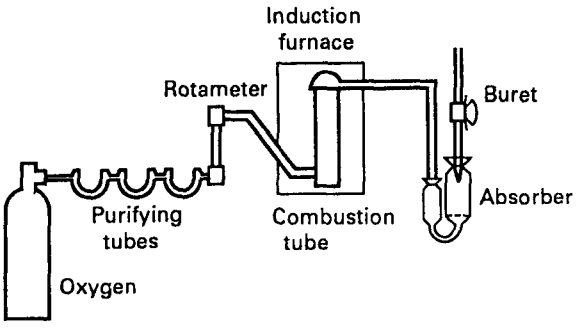


FIG. 2 SCHEMATIC ILLUSTRATION OF INDUCTION-TYPE FURNACE

7.16 *Sulfuric Acid* (relative density 1.84) — Concentrated sulfuric acid (H_2SO_4). **Warning** — Poison. Corrosive. Strong oxidizer.

7.17 *Vanadium Pentoxide,* anhydrous, powdered V_2O_5.

8. Sampling

8.1 Take samples in accordance with the instructions in Practice D 4057.

9. Preparation of Apparatus

9.1 *Induction-Type Furnace* — Assemble the apparatus according to the instructions furnished by the manufacturer. Purify the oxygen by passing it through *(1)* H_2SO_4 (relative density 1.84), *(2)* Ascarite, and *(3)* magnesium perchlorate [$Mg(ClO_4)_2$] or phosphorus pentoxide (P_2O_5) (**Warning** — see para. 7.4). Connect a rotameter between the purifying train and the furnace. Insert a small glass-wool plug in the upper end of the glass tubing connecting the furnace with the absorber to catch oxides of tin. Connect the exit end of the combustion tube to the absorber with glass tubing, using gum rubber tubing to make connections. Position the absorber so as to make this delivery line as short as possible. Figure 2 illustrates schematically the assembled apparatus. Adjust the oxygen flow to 1 ± 0.05 L/min. Add 65 mL of HCl (3 + 197) and 2 mL of starch-iodide solution to the absorber. Add a sufficient amount of the appropriate standard KIO_3 solution (Table 1) to produce a faint blue color. This color will serve as the end point for the titration. Adjust the buret to zero. Turn on the furnace filament switch and allow at least 1 min warm-up before running samples (**Warning** — see 7.4).

9.2 *Resistance-Type Furnace* — Assemble the apparatus according to the instructions furnished by the manufacturer. Purify the oxygen by passing it through *(1)*

TABLE 1
SAMPLE WEIGHT FOR INDUCTION FURNACE

Sulfur Content, %	Weight of Sample to Be Taken, mg	Normality of Standard KIO_3 Solution for Titration
0 to 2	90[A]	0.006238
2 to 4	50 to 90	0.006238
4 to 10	50 to 90	0.01248
Over 10	12.1.1	(Note 2)

[A] Approximate.

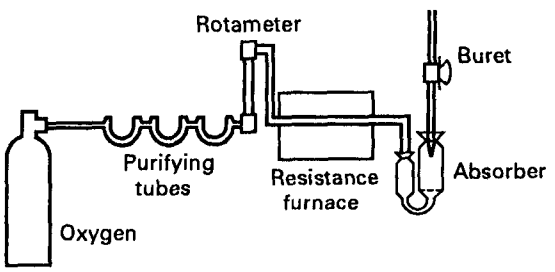


FIG. 3 SCHEMATIC ILLUSTRATION OF RESISTANCE-TYPE FURNACE

TABLE 2
SAMPLE WEIGHT FOR RESISTANCE FURNACE

Sulfur Content, %	Weight of Sample to Be Taken, mg	Normality of Standard KIO_3 Solution for Titration
0 to 2	100 to 200	0.006238
2 to 5	100 to 200	0.01248
5 to 10	100 to 200	0.06238
Over 10	(Note 2)	(Note 2)

H_2SO_4 (relative density 1.84), *(2)* Ascarite, and *(3)* $Mg(ClO_4)_2$ or P_2O_5 (**Precaution** — see Note 3). Connect a rotameter between the purifying train and the furnace. Figure 3 illustrates schematically the assembled apparatus. Turn on the current and adjust the furnace control to maintain a constant temperature of 1316 ± 14°C (2400 ± 25°F). Adjust the oxygen flow rate to 2 ± 0.1 L/min. Add 65 mL of HCl (3 ± 197) and 2 mL of starch-iodide solution to the absorber. Add a few drops of the appropriate standard KIO_3 solution (Table 2) to produce a faint blue color. Adjust the buret to zero.

9.3 *Resistance-Type Furnace-IR Detection* — Assemble and adjust apparatus according to manufacturer's instructions. Initialize microprocessor, check power supplies, set oxygen pressure and flows and set furnace temperature to 1371°C (2500°F).

9.3.1 Condition a fresh anhydrone scrubber with four coal samples.

9.3.2 Calibrate the automatic balance according to manufacturer's instructions.

10. Standardization

10.1 *For Iodate Methods:*

10.1.1 *Determination of Alum Factor:*

10.1.1.1 Because these rapid combustion methods involve the reversible reaction $2SO_2 + O_2 = 2SO_3$, it is not possible to evolve all the sulfur as SO_2. The equilibrium of the reaction is temperature dependent and, in an oxygen atmosphere above 1316°C, about 97% of the sulfur is present as SO_2. To assure that the furnace is in proper adjustment and that its operation produces acceptably high temperature, potassium alum is employed for standardizing the apparatus. Depending on the type of combustion equipment used, proceed as described in Sections 10 to 13 to determine the alum factor. Use 15 mg weighed to ±0.1 mg of potassium alum for this determination. Use the same materials in the determination of the alum and standardization factors as for the unknown samples. For example, V_2O_5 has a definite effect and should be included if used for unknowns as recommended in the procedure with the resistance-type furnace.

10.1.1.2 Calculate the alum factor as follows:

$$\text{Alum factor } (AF) = (S_A \times W_A)/[100\ (V_a - V_b) \times C_1] \quad (1)$$

where:

S_A = mass percent sulfur in potassium alum used,
W_A = milligrams of potassium alum used,
V_a = millilitres of standard KIO_3 solution used in determining the alum factor,
V_b = millilitres of standard KIO_3 solution used in the blank determination, and
C_1 = sulfur equivalent of the standard KIO_3 solution used in determining the alum factor, mg/mL.

10.1.1.3 The alum factor should be in the range from 1.02 to 1.08. If values smaller than 1.02 are observed, confirm independently the sulfur content of the alum and the sulfur equivalent of the KIO_3 solution before repeating the alum factor determination. If values larger than 1.08 are observed, make adjustments in the equipment in accordance with the manufacturer's recommendation and repeat the alum factor determination.

10.1.2 *Determination of Standardization Factor:*

10.1.2.1 Because effects such as sample volatility can also affect the relative recovery as SO_2 of the sulfur originally present in the sample, it is necessary to determine a standardization factor. Proceed as described in Sections 10 to 13, using an oil sample of similar type

to the unknown sample and of accurately known sulfur content.

10.1.2.2 For IR detection, determine and load the microprocessor with the calibration factor for the particular type of sample to be analyzed (lubricating oil, petroleum coke, residual fuel) as recommended by the manufacturer.

10.1.2.3 Calculate the standardization factor as follows:

$$\text{Standardization factor } (F_s) = (S_s \times W_s)/[100\ (V_s - V_b) \times C] \quad (2)$$

where:

S_s = mass percent sulfur in standardization sample used,
W_s = milligrams of standardization sample used,
V_b = millilitres of standard KIO_3 solution used in the blank determination,
V_s = millilitres of standard KIO_3 solution used in determining the standardization factor, and
C = sulfur equivalent of the standard KIO_3 solution used in determining the standardization factor, mg/mL.

10.1.3 *Quality Control* — Run a suitable analytical quality control sample several times daily. When the observed value lies between acceptable limits on a quality control chart, proceed with sample determinations.

11. Preparation of Coke

11.1 It is assumed that a representative sample has been received for analysis.

11.2 Grind and sieve the sample received so as to pass a 60-mesh (250-mm) sieve.

11.3 Dry the sieved material to constant weight at 105 to 110°C.

12. Procedure With Induction-Type Furnace

12.1 *Sample Preparation* — Add a 3.2 to 4.8-mm ($^1/_8$ to $^3/_{16}$-in.) layer of alundum or magnesium oxide to a sample crucible. Make a depression in the bed with the end of a stirring rod. Weigh the crucible to 0.1 mg. Weigh into the depression the proper amount of sample according to Table 1 (12.1.1) (Note 2). Cover the sample with a separator disk (Note 3). Place on the separator disk the predetermined amount of iron chips necessary to obtain the required temperature (6.1.1.2). This is usually between 1.2 and 2.0 g, but should be held constant with ±0.05 g. Sprinkle about 0.1 g of tin on the iron. Cover the crucible with a lid and place on the furnace pedestal.

12.1.1 Under no conditions shall an organic sample larger than 100 mg be burned in an induction-type furnace.

NOTE 2 — More concentrated KIO_3 solutions, such as the 0.06238 *N* solution, may be found more convenient for samples containing more than 10% sulfur. The sample size and KIO_3 concentration should be chosen so that not more than 25 mL of titrant is needed.

NOTE 3 — The use of the separator disk is optional.

12.2 *Combustion and Titration* — Turn on the plate current switch. After about 1 min for warm-up, raise the pedestal and lock into position. The plate current will fluctuate for a few seconds and should gradually rise to a maximum value. Add the appropriate standard KIO_3 solution (Table 1) to the absorber to maintain the blue color. Should the absorber solution become completely colorless, discard the determination. Make KIO_3 additions as the rate of evolution of SO_2 diminishes such that, when combustion is completed, the intensity of the blue color is the same as the initial intensity. Combustion is complete when this color remains for at least 1 min and the plate current has dropped considerably. Record the volume of KIO_3 solution required to titrate the SO_2 evolved.

12.3 *Blank Determination* — Make a blank determination whenever a new supply of crucibles, materials, or reagents is used. Follow the preceding procedure, but omit the sample.

13. Procedure With Resistance-Type Furnace

13.1 *Sample Preparation* — Weigh into a combustion boat the proper amount of sample according to Table 2. Add 100 ± 5 mg of vanadium pentoxide and completely cover the mixture with Alundum.

13.2 *Combustion and Titration* — Place the boat in the cool portion of the combustion tube, near the entrance. To proceed with the combustion, push the boat containing the sample progressively into the hotter zone of the combustion tube using the equipment provided by the manufacturers. The boat should be advanced as rapidly as possible consistent with the rate of evolution of SO_2. Add the appropriate standard KIO_3 solution (Table 2) to the absorber to maintain the blue color. Should the absorber solution become completely colorless, discard the determination. Make KIO_3 additions as the rate of evolution of SO_2 diminishes such that, when combustion is completed, the intensity of the blue color is the same as the initial intensity. Combustion is complete when this color remains for at least 1 min. Record the volume of KIO_3 solution required to titrate the SO_2 evolved.

13.3 *Blank Determination* — Make a blank determination whenever a new supply of combustion boats, materials, or reagents is used. Follow the above procedure, but omit the sample.

14. Procedure With Resistance Furnace-IR Detection

14.1 Allow the system to warm up and the furnace to reach operating temperature.

14.2 After homogeneity of the sample is assured, select the sample size as follows: for liquid samples, take up to 0.13 g for analysis and for solid samples, take up to 0.4 g for analysis. In each case, mass percent sulfur times weight of sample must be less than or equal to four in the case of the SC32 instrument, and two in the case of the SC132 instrument. For other instruments, consult the manufacturer's instructions.

14.3 Determine and store the system blank value.

14.4 Weigh the samples into combustion boats and record the net weights. It is possible to weigh and store several weights in the microprocessor before beginning a series of burns.

14.4.1 Fill the combustion boat to one-third capacity with evenly spread MgO powder.

14.4.2 Form a slight trench in the MgO powder with a scoop.

14.4.3 Place the combustion boat on the balance and weigh an appropriate amount of the sample into the trench in the MgO powder. Enter the weight.

14.4.4 Remove the combustion boat from the balance and add MgO powder until the combustion boat is filled to two-thirds capacity.

NOTE 4 — If unacceptable repeatability is encountered for particular oil samples, combustion promoter such as V_2O_5 or the LECO product *Com-Aid* can be substituted for the MgO.

14.5 Initiate oxygen flow and load boat into furnace.

14.6 When the analysis is complete, read the result from the microprocessor.

14.7 Remove the expended combustion boat from the furnace.

14.8 Make repeated runs until two results differ by less than the repeatability of the method.

15. Calculation

15.1 *Calculation for Iodate Detection* — Calculate the sulfur content of the sample as follows:

$$\text{Sulfur, mass \%} = [100\,(V - V_b) \times F_s \times C]/W \quad (3)$$

where:

V = standard KIO_3 solution, mL, used in the analysis,
V_b = standard KIO_3 solution, mL, used in the blank determination,
F_s = standardization factor (see 10.1.2),
C = sulfur equivalent of the standard KIO_3 solution used in the analysis, mg/mL, and
W = milligrams of sample used in the analysis.

15.2 *Calculation for IR Detection:*

15.2.1 Report all results using the microprocessor.

15.2.2 Report the average of two results.

16. Report

16.1 In the range from 0.05 to 5.00 mass % sulfur, report to the nearest 0.01 mass %. In the range from 5 to 30 mass % sulfur, report to the nearest 0.1 mass %.

17. Quality Control

17.1 Confirm the performance of the test procedure by analyzing a quality control sample that is stable and representative of the sample interest.

17.1.1 When the quality control/quality assurance protocols are already established in the testing facility, these may be used to confirm the reliability of the test result.

17.1.2 When there is no quality control/quality assurance protocol established in the testing facility, Appendix X1 can be used for this purpose.

18. Precision and Bias

18.1 *For Petroleum Products by Iodate and IR Methods* — The precision of this test method as determined by statistical examination of interlaboratory results is as follows:

18.1.1 *Repeatability* — The difference between two test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in twenty:

Sulfur, Mass, % Range	Repeatability Iodate	IR[8]
0.0 to 0.5	0.05	0.04
0.5 to 1.0	0.07	0.07
1.0 to 2.0	0.10	0.09
2.0 to 3.0	0.16	0.12
3.0 to 4.0	0.22	0.13
4.0 to 5.0	0.24	0.16

18.1.2 *Reproducibility* — The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in twenty:

Sulfur, Mass, % Range	Reproducibility Iodate	IR[8]
0.0 to 0.5	0.08	0.13
0.5 to 1.0	0.11	0.21
1.0 to 2.0	0.17	0.27
2.0 to 3.0	0.26	0.38
3.0 to 4.0	0.40	0.44
4.0 to 5.0	0.54	0.49

18.2 *For Petroleum Cokes by Iodate and IR Methods* — The precision of the test method as determined by statistical examination of interlaboratory results is as follows:

18.2.1 *Repeatability* — The difference between two test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in twenty:

$$r = 0.05X \quad (4)$$

where X is the average of the two test results.

18.2.2 *Reproducibility* — The difference between two single and independent results obtained by different operators working in different laboratories on identical test material could, in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in twenty:

$$R = 0.22X \quad (5)$$

where X is the average of the two test results.

18.3 *Bias* — The bias of the procedure in this test method is being determined.

19. Keywords

19.1 furnace; high temperature; induction furnace; iodate titration; IR detection; petroleum; resistance; sulfur; titration

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL

X1.1 Confirm the performance of the instrument or the test procedure by analyzing a quality control (QC) sample.

X1.2 Prior to monitoring the measurement process, the user of the method needs to determine the average value and conrol limits of the QC sample (see Practice D 6299 and *ASTM MNL 7*).

X1.3 Record the QC results and analyze by control charts or other statistically equivalent techniques to ascertain the statistical control status of the total testing process (see Practice D 6299 and *ASTM MNL 7*). Any out-of-control data should trigger investigation for root cause(s).

X1.4 In the absence of explicit requirements given in the test method, the frequency of QC testing is dependent on the criticality of the quality being measured, the demonstrated stability of the testing process, and customer requirements. Generally, a QC sample is analyzed each testing day with routine samples. The QC frequency should be increased if a large number of samples are routinely analyzed. However, when it is demonstrated that the testing is under statistical control, the QC testing frequency may be reduced. The QC sample precision should be checked against the ASTM method precision to ensure data quality.

X1.5 It is recommended that, if possible, the type of QC that is regularly tested be representative of the material routinely analyzed. An ample supply of QC sample material should be available for the intended period of use, and must be homogenous and stable under the anticipated storage conditions.

X1.6 See Practice D 6299 and *ASTM MNL 7* for further guidance on QC and Control Charting techniques.

STANDARD TEST METHOD FOR LIQUID PENETRANT EXAMINATION

SE-165

(Identical with ASTM Specification E 165-02)

1. Scope

1.1 This test method covers procedures for penetrant examination of materials. They are nondestructive testing methods for detecting discontinuities that are open to the surface such as cracks, seams, laps, cold shuts, laminations, through leaks, or lack of fusion and are applicable to in-process, final, and maintenance examination. They can be effectively used in the examination of nonporous, metallic materials, both ferrous and nonferrous, and of nonmetallic materials such as glazed or fully densified ceramics, certain nonporous plastics, and glass.

1.2 This test method also provides a reference:

1.2.1 By which a liquid penetrant examination process recommended or required by individual organizations can be reviewed to ascertain its applicability and completeness.

1.2.2 For use in the preparation of process specifications dealing with the liquid penetrant examination of materials and parts. Agreement by the user and the supplier regarding specific techniques is strongly recommended.

1.2.3 For use in the organization of the facilities and personnel concerned with the liquid penetrant examination.

1.3 This test method does not indicate or suggest criteria for evaluation of the indications obtained. It should be pointed out, however, that after indications have been produced, they must be interpreted or classified and then evaluated. For this purpose there must be a separate code or specification or a specific agreement to define the type, size, location, and direction of indications considered acceptable, and those considered unacceptable.

1.4 The values stated in inch-pound units are to be regarded as the standard. SI units are provided for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)

D 516 Test Method for Sulfate Ion in Water

D 808 Test Method for Chlorine in New and Used Petroleum Products (Bomb Method)

D 1193 Specification for Reagent Water

D 1552 Test Method for Sulfur in Petroleum Products (High-Temperature Method)

D 4327 Test Method for Anions in Water in Chemically Suppressed Ion Chromatography

E 433 Reference Photographs for Liquid Penetrant Inspection

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing

E 1208 Test Method for Fluorescent Liquid Penetrant Examination Using the Lipophilic Post-Emulsification Process

E 1209 Test Method for Fluorescent Liquid Penetrant Examination Using the Water-Washable Process

E 1210 Test Method for Fluorescent Liquid Penetrant Examination Using the Hydrophilic Post-Emulsification Process

E 1219 Test Method for Fluorescent Liquid Penetrant Examination Using the Solvent-Removable Process

E 1220 Test Method for Visible Penetrant Examination Using the Solvent-Removable Process

E 1316 Terminology for Nondestructive Examinations

E 1418 Test Method for Visible Penetrant Examination Using the Water-Washable Process

2.2 *ASNT Documents:*

Recommended Practice SNT-TC-1A for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

2.4 *APHA Standard:*

429 Method for the Examination of Water and Wastewater

NAS-410 Certification and Qualification of Nondestructive Test Personnel

3. Terminology

3.1 The definitions relating to liquid penetrant examination, which appear in Terminology E 1316, shall apply to the terms used in this standard.

4. Summary of Test Method

4.1 A liquid penetrant which may be a visible or a fluorescent material is applied evenly over the surface being examined and allowed to enter open discontinuities. After a suitable dwell time, the excess surface penetrant is removed. A developer is applied to draw the entrapped penetrant out of the discontinuity and stain the developer. The test surface is then examined to determine the presence or absence of indications.

NOTE 1: The developer may be omitted by agreement between purchaser and supplier.

NOTE 2: **Caution** — Fluorescent penetrant examination shall not follow a visible penetrant examination unless the procedure has been qualified in accordance with 10.2, because visible dyes may cause deterioration or quenching of fluorescent dyes.

4.2 Processing parameters, such as surface precleaning, penetration time and excess penetrant removal methods, are determined by the specific materials used, the nature of the part under examination (that is, size, shape, surface condition, alloy), and type of discontinuities expected.

TABLE 1
CLASSIFICATION OF PENETRANT EXAMINATION TYPES AND METHODS

Type I — Fluorescent Penetrant Examination
Method A — Water-washable (see Test Method E 1209)
Method B — Post-emulsifiable, lipophilic (see Test Method E 1208)
Method C — Solvent removable (see Test Method E 1219)
Method D — Post-emulsifiable, hydrophilic (see Test Method E 1210)
Type II — Visible Penetrant Examination
Method A — Water-washable (see Test Method E 1418)
Method C — Solvent removable (see Test Method E 1220)

5. Significance and Use

5.1 Liquid penetrant examination methods indicate the presence, location and, to a limited extent, the nature and magnitude of the detected discontinuities. Each of the various methods has been designed for specific uses such as critical service items, volume of parts, portability or localized areas of examination. The method selected will depend accordingly on the service requirements.

6. Classification of Penetrations and Methods

6.1 Liquid penetrant examination methods and types are classified as shown in Table 1.

6.2 *Fluorescent penetrant examination* utilizes penetrants that fluoresce brilliantly when excited by black light (see 8.9.1.2). The sensitivity of fluorescent penetrants depends on their ability to be retained in the various size discontinuities during processing, then to bleed out into the developer coating and produce indications that will fluoresce. Fluorescent indications are many times brighter than their surroundings when viewed under black light illumination.

6.3 *Visible penetrant examination* uses a penetrant that can be seen in visible light. The penetrant is usually red, so that the indications produce a definite contrast with the white background of the developer. The visible penetrant process does not require the use of black light. However, visible penetrant indications must be viewed under adequate white light (see 8.9.2.1).

7. Types of Materials

7.1 *Liquid penetrant examination materials* (see Notes 3, 4, and 5) consist of fluorescent and visible penetrants,

emulsifiers (oil-base and water-base; fast and slow acting), solvent removers and developers. A family of liquid penetrant examination materials consists of the applicable penetrant and emulsifier or remover, as recommended by the manufacturer. Intermixing of materials from various manufacturers is not recommended.

NOTE 3: Refer to 9.1 for special requirements for sulfur, halogen and alkali metal content.

NOTE 4: **Caution** — While approved penetrant materials will not adversely affect common metallic materials, some plastics or rubbers may be swollen or stained by certain penetrants.

7.2 *Penetrants:*

7.2.1 *Post-Emulsifiable Penetrants* are designed to be insoluble in water and cannot be removed with water rinsing alone. They are designed to be selectively removed from the surface using a separate emulsifier. The emulsifier, properly applied and given a proper emulsification time, combines with the excess surface penetrant to form a water-washable mixture, which can be rinsed from the surface, leaving the surface free of fluorescent background. Proper emulsification time must be experimentally established and maintained to ensure that over-emulsification does not occur, resulting in loss of indications.

7.2.2 *Water-Washable Penetrants* are designed to be directly water-washable from the surface of the test part, after a suitable penetrant dwell time. Because the emulsifier is "built-in" to the water-washable penetrant, it is extremely important to exercise proper process control in removal of excess surface penetrant to ensure against overwashing. Water-washable penetrants can be washed out of discontinuities if the rinsing step is too long or too vigorous. Some penetrants are less resistant to overwashing than others.

7.2.3 *Solvent-Removable Penetrants* are designed so that excess surface penetrant can be removed by wiping until most of the penetrant has been removed. The remaining traces should be removed with the solvent remover (see 8.6.4.1). To minimize removal of penetrant from discontinuities, care should be taken to avoid the use of excess solvent. Flushing the surface with solvent to remove the excess penetrant is prohibited.

7.3 *Emulsifiers:*

7.3.1 *Lipophilic Emulsifiers* are oil-miscible liquids used to emulsify the excess oily penetrant on the surface of the part, rendering it water-washable. The rate of diffusion establishes the emulsification time. They are either slow- or fast-acting, depending on their viscosity and chemical composition, and also the surface roughness of the area being examined (see 8.6.2).

7.3.2 *Hydrophilic Emulsifiers* are water-miscible liquids used to emulsify the excess oily fluorescent penetrant on the surface of the part, rendering it water-washable (see 8.6.3). These water-base emulsifiers (detergent-type removers) are supplied as concentrates to be diluted with water and used as a dip or spray. The concentration, use and maintenance shall be in accordance with manufacturer's recommendations.

7.3.2.1 Hydrophilic emulsifiers function by displacing the excess penetrant film from the surface of the part through detergent action. The force of the water spray or air/mechanical agitation in an open dip tank provides the scrubbing action while the detergent displaces the film of penetrant from the part surface. The emulsification time will vary, depending on its concentration, which can be monitored by the use of a suitable refractometer.

7.4 *Solvent Removers* function by dissolving the penetrant, making it possible to wipe the surface clean and free of excess penetrant as described in 8.6.4.

7.5 *Developers* — Development of penetrant indications is the process of bringing the penetrant out of open discontinuities through blotting action of the applied developer, thus increasing the visibility of the indications.

7.5.1 *Dry Powder Developers* are used as supplied (that is, free-flowing, non-caking powder) in accordance with 8.8.2. Care should be taken not to contaminate the developer with fluorescent penetrant, as the penetrant specks can appear as indications.

7.5.2 *Aqueous Developers* are normally supplied as dry powder particles to be either suspended or dissolved (soluble) in water. The concentration, use and maintenance shall be in accordance with manufacturer's recommendations (see 8.8.3).

NOTE 5: **Caution** — Aqueous developers may cause stripping of indications if not properly applied and controlled. The procedure should be qualified in accordance with 10.2.

7.5.3 *Nonaqueous Wet Developers* are supplied as suspensions of developer particles in a nonaqueous solvent carrier ready for use as supplied. Nonaqueous, wet developers form a coating on the surface of the part when dried, which serves as the developing medium (see 8.8.4).

NOTE 6: **Caution** — This type of developer is intended for application by spray only.

7.5.4 *Liquid Film Developers* are solutions or colloidal suspensions of resins/polymer in a suitable carrier. These developers will form a transparent or translucent coating on the surface of the part. Certain types of film developer may be stripped from the part and retained for record purposes (see 8.8.5).

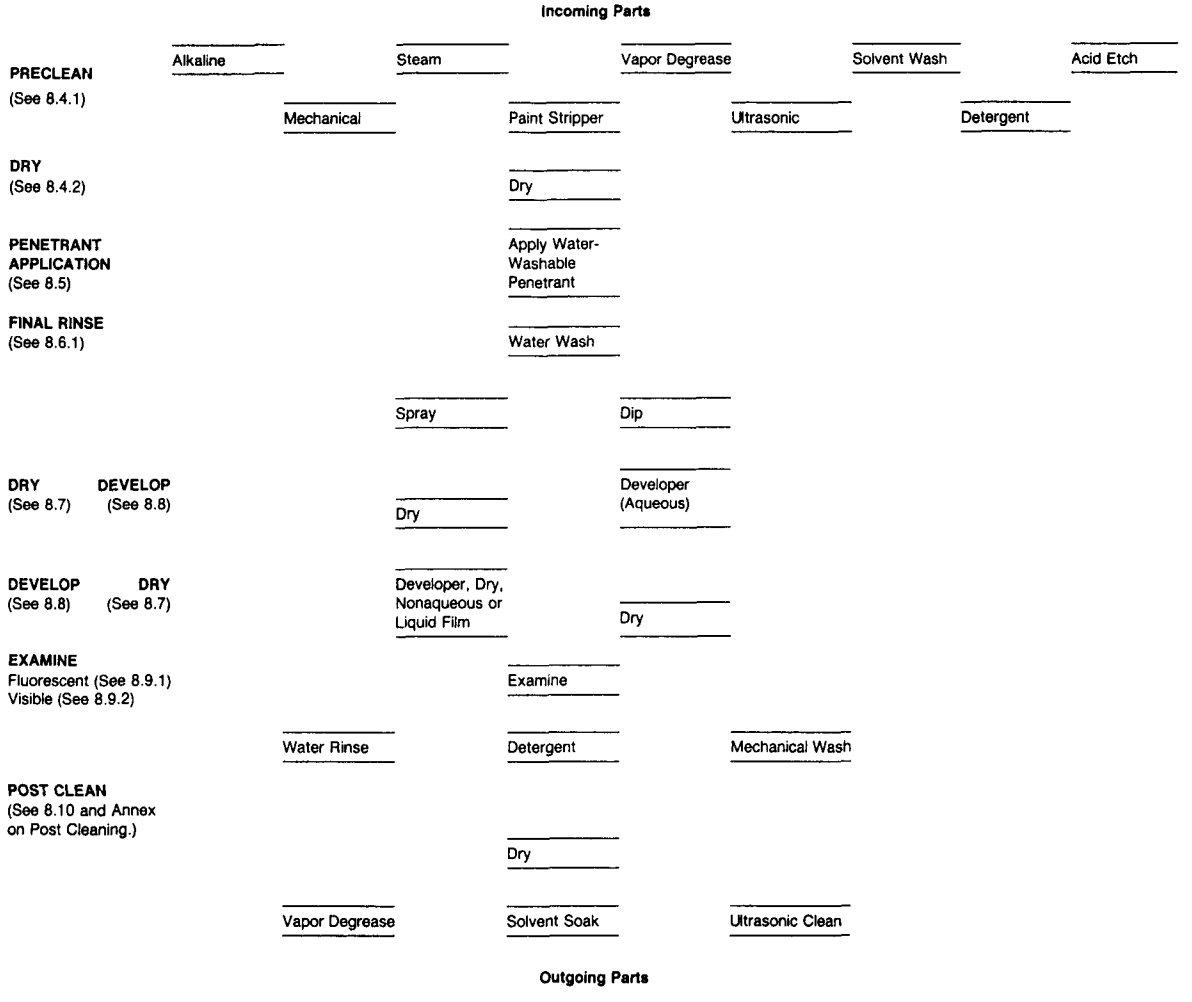


FIG. 1 GENERAL PROCEDURE FLOWSHEET FOR PENETRANT EXAMINATION USING THE WATER-WASHABLE PROCESS (TEST METHOD E 1209 FOR FLUORESCENT AND TEST METHOD E 1220 FOR VISIBLE LIGHT)

8. Procedure

8.1 The following general processing guidelines apply (see Figs. 2, 3, and 4) to both fluorescent and visible penetrant examination methods (see Fig. 1).

8.2 *Temperature Limits* — The temperature of the penetrant materials and the surface of the part to be processed should be between 50 and 100°F (10 and 38°C). Where it is not practical to comply with these temperature limitations, qualify the procedure as described in 10.2 at the temperature of intended use and as agreed to by the contracting parties.

8.3 *Surface Conditioning Prior to Penetrant Examination* — Satisfactory results usually may be obtained on surfaces in the as-welded, as-rolled, as-cast, or as-forged conditions (or for ceramics in the densified conditions). Sensitive penetrants are generally less easily rinsed away and are therefore less suitable for rough surfaces. When only loose surface residuals are present, these may be removed by wiping with clean lint-free cloths. However, precleaning of metals to remove processing residuals such as oil, graphite, scale, insulating materials, coatings, and so forth, should be done using cleaning solvents, vapor degreasing or chemical removing processes. Surface conditioning by grinding, machining, polishing or etching shall follow shot, sand, grit or vapor blasting to remove the peened skin and when penetrant entrapment in surface irregularities might mask the indications of unacceptable discontinuities or otherwise interfere with the effectiveness of the examination. For metals, unless otherwise specified, etching shall be performed when evidence exists that previous cleaning, surface treatments or service

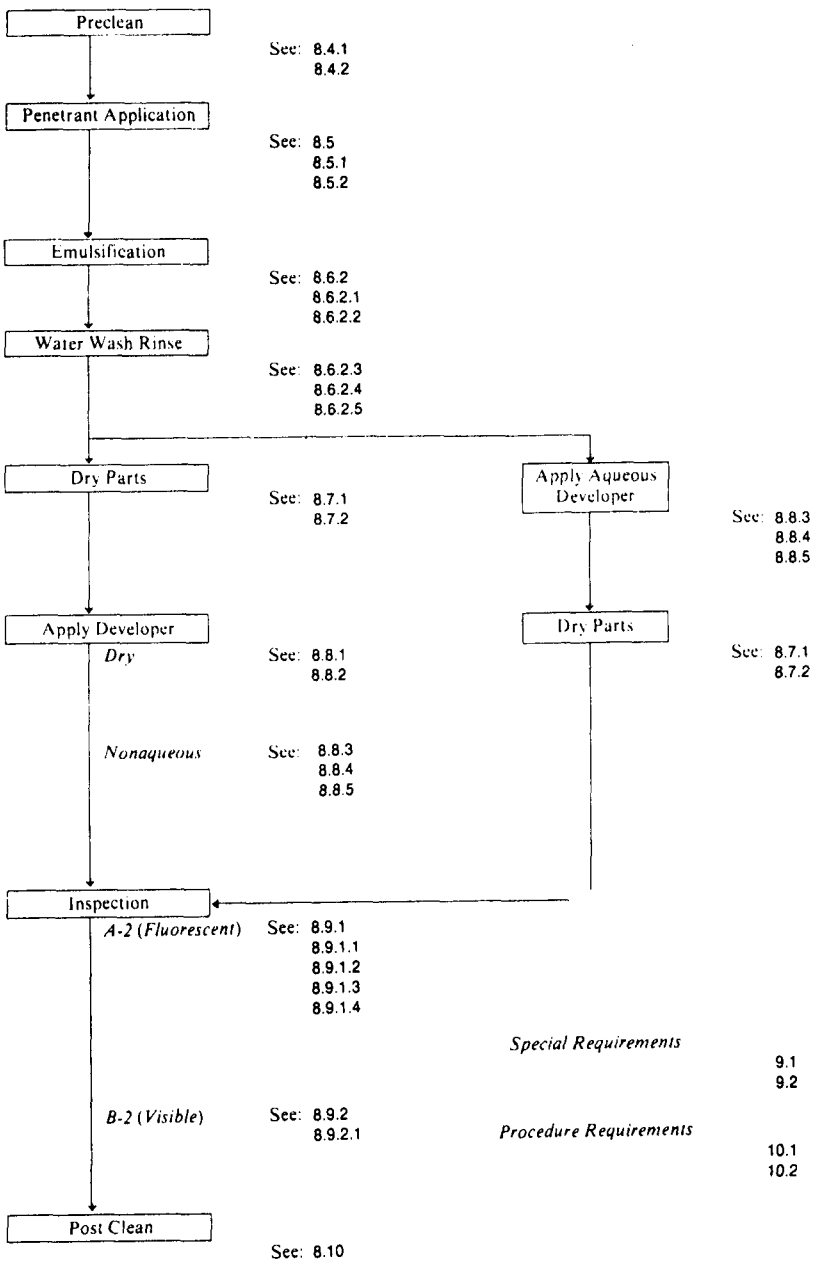


FIG. 2 TYPE 2 — POST EMULSIFIABLE PROCEDURES A-2 (FLUORESCENT) AND B-2 (VISIBLE)

usage have produced a surface condition that degrades the effectiveness of penetrant examination. (See Annex A1.1.1.8 for precautions.)

NOTE 7: When agreed between purchaser and supplier, grit blasting without subsequent etching may be an acceptable cleaning method.

NOTE 8: **Caution** — Sand or shot blasting may possibly close discontinuities and extreme care should be used with grinding and machining operations to avoid masking discontinuities.

NOTE 9: For structural or electronic ceramics, surface preparation by grinding, sand blasting and etching for penetrant examination is not recommended because of the potential for damage.

8.4 *Removal of Surface Contaminants:*

8.4.1 *Precleaning* — The success of any penetrant examination procedure is greatly dependent upon the surrounding surface and discontinuity being free of any contaminant (solid or liquid) that might interfere with the

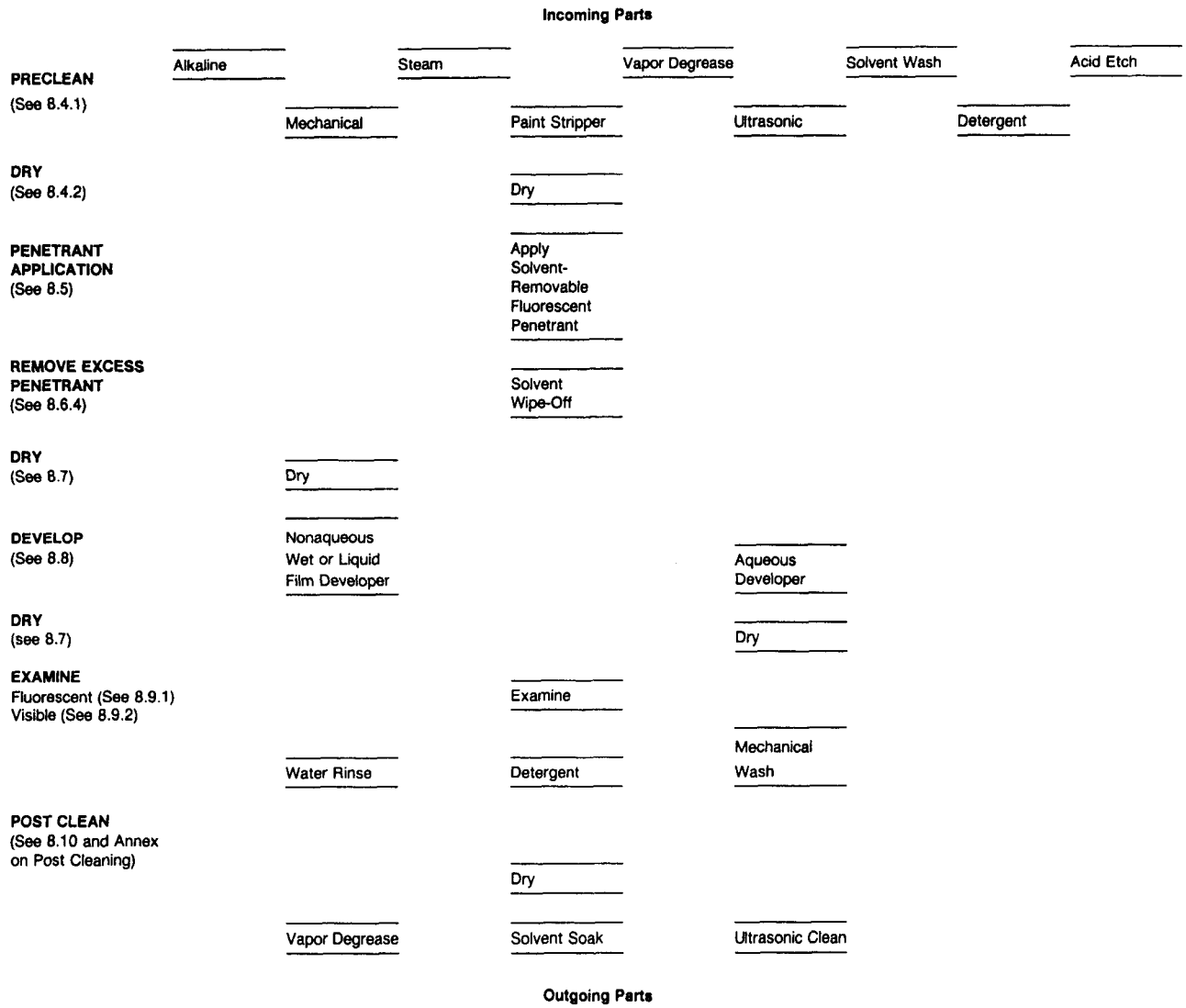


FIG. 3 SOLVENT-REMOVABLE PENETRANT EXAMINATION GENERAL PROCEDURE FLOWSHEET (TEST METHOD E 1219 FOR FLUORESCENT AND TEST METHOD E 1220 FOR VISIBLE LIGHT)

penetrant process. All parts or areas of parts to be examined must be clean and dry before the penetrant is applied. If only a section of a part, such as a weld, including the heat affected zone is to be examined, all contaminants shall be removed from the area being examined as defined by the contracting parties. "Clean" is intended to mean that the surface must be free of rust, scale, welding flux, weld spatter, grease, paint, oily films, dirt, and so forth, that might interfere with the penetrant process. All of these contaminants can prevent the penetrant from entering discontinuities (see Annex or Cleaning of Parts and Materials).

NOTE 10: **Caution** — Residues from cleaning processes such as strong alkalies, pickling solutions and chromates, in particular, may adversely react with the penetrant and reduce its sensitivity and performance.

8.4.2 *Drying after Cleaning* — It is essential that the surface of parts be thoroughly dry after cleaning, since any liquid residue will hinder the entrance of the penetrant. Drying may be accomplished by warming the parts in drying ovens, with infrared lamps, forced hot air, or exposure to ambient temperature.

8.5 *Penetrant Application* — After the part has been cleaned, dried, and is within the specified temperature

TABLE 2
RECOMMENDED MINIMUM DWELL TIMES

Material	Form	Type of Discontinuity	Dwell Times[A] (minutes) Penetrant[B]	Developer[C]
Aluminum, magnesium, steel, brass and bronze, titanium and high-temperature alloys	castings and welds	cold shuts, porosity, lack of fusion, cracks (all forms)	5	10
	wrought materials — extrusions, forgings, plate	laps, cracks (all forms)	10	10
Carbide-tipped tools		lack of fusion, porosity, cracks	5	10
Plastic	all forms	cracks	5	10
Glass	all forms	cracks	5	10
Ceramic	all forms	cracks, porosity	5	10

[A] For temperature range from 50 to 100°F (10 to 38°C) for fluorescent penetrants and 50 to 125°F (10 to 52°C) for visible penetrant.
[B] Maximum penetrant dwell time in accordance with 8.5.2.
[C] Development time begins as soon as wet developer coating has dried on surface of parts (recommended minimum). Maximum development time in accordance with 8.8.6.

range, the penetrant is applied to the surface to be examined so that the entire part or area under examination is completely covered with penetrant.

8.5.1 *Modes of Application* — There are various modes of effective application of penetrant such as dipping, brushing, flooding, or spraying. Small parts are quite often placed in suitable baskets and dipped into a tank of penetrant. On larger parts, and those with complex geometries, penetrant can be applied effectively by brushing or spraying. Both conventional and electrostatic spray guns are effective means of applying liquid penetrants to the part surfaces. Electrostatic spray application can eliminate excess liquid build-up of penetrant on the part, minimize overspray, and minimize the amount of penetrant entering hollow-cored passages which might serve as penetrant reservoirs, causing severe bleedout problems during examination. Aerosol sprays are conveniently portable and suitable for local application.

NOTE 11: **Caution** — Not all penetrant materials are suitable for electrostatic spray applications, so tests should be conducted prior to use.

NOTE 12: **Warning** — With spray applications, it is important that there be proper ventilation. This is generally accomplished through the use of a properly designed spray booth and exhaust system.

8.5.2 *Penetrant Dwell Time* — After application, allow excess penetrant to drain from the part (care should be taken to prevent pools of penetrant from forming on the part), while allowing for proper penetrant dwell time (see Table 2). The length of time the penetrant must remain on the part to allow proper penetration should be as recommended by the penetrant manufacturer. Table 2, however, provides a guide for selection of penetrant dwell times for a variety of materials, forms, and types of discontinuity. Unless otherwise specified, the dwell time shall not exceed the maximum recommended by the manufacturer.

NOTE 13: For some specific applications in structural ceramics (for example, detecting parting lines in slip-cast material), the required penetrant dwell time should be determined experimentally and may be longer than that shown in Table 1 and its notes.

8.6 *Penetrant Removal*

8.6.1 *Water Washable:*

8.6.1.1 *Removal of Excess Penetrants* — After the required penetration time, the excess penetrant on the surface being examined must be removed with water, usually a washing operation. It can be washed off manually, by the use of automatic or semi-automatic water-spray equipment or by immersion. For immersion rinsing, parts are completely immersed in the water bath with air or mechanical agitation. Accumulation of water in pockets or recesses of the surface must be avoided. If the final rinse step is not effective, as evidenced by excessive residual surface penetrant after rinsing, dry (see 8.7) and reclean the part, then reapply the penetrant for the prescribed dwell time.

(a) The temperature of the water should be relatively constant and should be maintained within the range of 50 to 100°F (10 to 38°C).

(b) Spray-rinse water pressure should not be greater than 40 psi (280 kPa).

(c) Rinse time should not exceed 120 s unless otherwise specified by part of material specification.

NOTE 14: **Caution** — Avoid overwashing. Excessive washing can cause penetrant to be washed out of discontinuities. With fluorescent penetrant methods perform the rinsing operation under black light so that it can be determined when the surface penetrant has been adequately removed.

8.6.1.2 *Removal by Wiping* — In special applications, penetrant removal may be performed by wiping the surface with a clean, absorbent material dampened with water until the excess surface penetrant is removed, as determined by examination under black light for fluorescent methods and white light for visible methods.

8.6.2 *Lipophilic Emulsification:*

8.6.2.1 *Application of Emulsifier* — After the required penetration time, the excess penetrant on the part must be emulsified by immersing or flooding the parts with the required emulsifier (the emulsifier combines with the excess surface penetrant and makes the mixture removable with water rinsing). After application of the emulsifier, the parts are drained in a manner that prevents the emulsifier from pooling on the part(s).

8.6.2.2 *Emulsification Dwell Time* begins as soon as the emulsifier has been applied. The length of time that the emulsifier is allowed to remain on a part and in contact with the penetrant is dependent on the type of emulsifier employed and the surface condition (smooth or rough). Nominal emulsification time should be as recommended by the manufacturer. The actual emulsification time must be determined experimentally for each specific application. The surface finish (roughness) of the part is a significant factor in the selection of and in the emulsification time of an emulsifier. Contact time should be kept to the least possible time consistent with an acceptable background and should not exceed the maximum time specified for the part or material.

8.6.2.3 *Post Rinsing* — Effective post rinsing of the emulsified penetrant from the surface can be accomplished using either manual, semi-automated, or automated water immersion or spray equipment or combinations thereof.

8.6.2.4 *Immersion* — For immersion post rinsing, parts are completely immersed in the water bath with air or mechanical agitation. The time and temperature should be kept constant.

(a) The maximum dip-rinse time should not exceed 120 s unless otherwise specified by part or material specification.

(b) The temperature of the water should be relatively constant and should be maintained within the range of 50 to 100°F (10 to 38°C). **Caution:** A touch-up rinse may be necessary after immersion.

8.6.2.5 *Spray Post Rinsing* — Effective post rinsing following emulsification can also be accomplished by either manual or automatic water spray rinsing of the parts as follows:

(a) Control rinse water temperature within the range of 50 to 100°F (10 to 38°C).

(b) Spray rinse water pressure should be in accordance with manufacturers' recommendations.

(c) The maximum spray rinse time should not exceed 120 s unless otherwise specified by part or materials specification.

8.6.2.6 *Rinse Effectiveness* — If the emulsification and final rinse step is not effective, as evidenced by excessive residual surface penetrant after emulsification and rinsing, dry (see 8.7) and reclean the part and reapply the penetrant for the prescribed dwell time.

8.6.3 *Hydrophilic Emulsification:*

8.6.3.1 *Prerinsing* — Directly after the required penetration time, it is recommended that the parts be prerinsed with water prior to emulsification (8.6.3.3). This step allows for the removal of excess surface penetrant from the parts prior to emulsification so as to minimize the degree of penetrant contamination in the hydrophilic emulsifier bath, thereby extending its life. In addition, prerinsing of penetrated parts minimizes possible oily penetrant pollution in the final rinse step of this process. This is accomplished by collecting the prerinsings in a holding tank, separating the penetrant from water.

8.6.3.2 *Prerinsing Controls* — Effective prerinsing is accomplished by either manual or automated water spray rinsing of the parts as follows:

(a) Water should be free of contaminants that could clog spray nozzles or leave a residue on parts.

(b) Control water temperature within the range of 50 to 100°F (10 to 38°C).

(c) Spray rinse at a water pressure of 25 to 40 psi (175 to 275 kPa).

(d) Prerinse time should be the least possible time (nominally 60 s maximum) to provide a consistent residue of penetrant on parts. Wash time is to be as specified by the part or material specification.

(e) Remove water trapped in cavities using filtered shop air at a nominal pressure 25 psi (175 kPa) or a suction device to remove water from pooled areas.

8.6.3.3 *Application of Emulsifier* — After the required penetration time and following the prerinse, the residual surface penetrant on part(s) must be emulsified by immersing the part(s) in a hydrophilic emulsifier bath (8.6.3.4) or by spraying the part(s) with the emulsifier (8.6.3.5) thereby rendering the remaining residual surface penetrant water-washable in the final rinse station (8.6.3.6).

8.6.3.4 *Immersion* — For immersion application, parts are completely immersed in the emulsifier bath. The hydrophilic emulsifier should be gently agitated throughout the contact cycle.

(a) Bath concentration should be as recommended by the manufacturer. Most hydrophilic emulsifiers are used within the range of 20 to 33% in water. Nominal use concentration for immersion applications is 20%.

(b) Bath temperatures should be maintained between 50 and 100°F (10 to 38°C).

(c) Immersion contact time should be kept to the minimum time consistent with an acceptable background and should not exceed 120 s or the maximum time stipulated by the part or material specification.

(d) Emulsifier drain time begins immediately after parts have been withdrawn from the emulsifier tank and continues until the parts are washed in the final rinse station (8.6.3.6). This drain time should be kept to a minimum to avoid over emulsification and should not exceed 90 s.

8.6.3.5 *Spray Application* — For spray application following the prerinse step, parts are emulsified by the spray application of an emulsifier. All part surfaces should be evenly and uniformly sprayed to effectively emulsify the residual penetrant on part surfaces to render it water-washable.

(a) The concentration of the emulsifier for spray application should be in accordance with the manufacturer's recommendations, but should not exceed 5%.

(b) Temperature to be maintained at 50 to 100°F (10 to 38°C).

(c) The spray pressure should be 25 psi (175 kPa) max for air and 40 psi (280 kPa) max for water.

(d) Contact time should be kept to the minimum consistent with an acceptable background and should not exceed 120 s or the maximum time stipulated by the part or material specification.

8.6.3.6 *Post-Rinsing of Hydrophilic Emulsified Parts* — Effective post-rinsing of emulsified penetrant from the surface can be accomplished using either manual, semi-automated, or automated water immersion or spray equipment or combinations thereof.

8.6.3.7 *Immersion Post-Rinsing* — Parts are to be completely immersed in the water bath with air or mechanical agitation.

(a) The temperature of the water should be relatively constant and should be maintained within the range of 50 to 100°F (10 to 38°C).

(b) The maximum dip rinse time should not exceed 120 s unless otherwise specified by part or material specification. **Caution:** A touch-up rinse may be necessary after immersion.

8.6.3.8 *Spray Post-Rinsing* — Following emulsification parts can be post-rinsed by water spray rinsing as follows:

(a) Control rinse water temperature within the range of 50 to 100°F (10 to 38°C).

(b) Spray rinse water pressure should be in accordance with manufacturer's instructions.

(c) The maximum spray rinse time should not exceed 120 s unless otherwise specified by part or materials specification.

8.6.3.9 If the emulsification and final rinse steps are not effective, as evidenced by excessive residual surface penetrant after emulsification and rinsing, dry (see 8.7) and reclean the part and reapply the penetrant for the prescribed dwell time.

8.6.4 *Solvent-Removable Penetrants:*

8.6.4.1 *Removal of Excess Penetrant* — After the required penetration time, the excess penetrant is removed insofar as possible, by using wipers of a dry, clean, lint-free material and repeating the operation until most traces of penetrant have been removed. Then using a lint-free material lightly moistened with solvent remover the remaining traces are gently wiped to avoid removing penetrant from discontinuities. Avoid the use of excess solvent. If the wiping step is not effective, as evidenced by difficulty in removing the excess penetrant, dry the part (see 8.7), and reapply the penetrant for the prescribed dwell time. Flushing the surface with solvent following the application of the penetrant and prior to developing is prohibited.

8.7 *Drying* — Drying the surface of the part(s) is necessary prior to applying dry or nonaqueous developers or following the application of the aqueous developer. Drying time will vary with the size, nature, and number of parts under examination.

8.7.1 *Drying Parameters* — Components shall be air dried at room temperature or in a drying oven. Oven temperatures shall not exceed 160°F (71°C). Drying time shall only be that necessary to adequately dry the part. Components shall be removed from the oven immediately after drying. Components shall not be placed in the oven with pooled water or pooled aqueous solutions/suspensions.

8.7.2 *Drying Time Limits* — Do not allow parts to remain in the drying oven any longer than is necessary to dry the surface. Times over 30 min in the dryer may impair the sensitivity of the examination.

8.8 *Developer Application:*

8.8.1 *Modes of Application* — There are various modes of effective application of the various types of developers such as dusting, immersing, flooding or spraying. The size, configuration, surface condition, number of parts to be processed, and so forth, will influence the choice of developer application.

8.8.2 *Dry Powder Developer* — Dry powder developers should be applied immediately after drying in such a manner as to ensure complete part coverage. Parts can be immersed in a container of dry developer or in a fluid bed of dry developer. They can also be dusted with the powder developer through a hand powder bulb or a conventional or electrostatic powder gun. It is common and effective to apply dry powder in an enclosed dust chamber, which creates an effective and controlled dust cloud. Other means suited to the size and geometry of the specimen may be used, provided the powder is dusted evenly over the entire surface being examined. Excess powder may be removed by shaking or tapping the part, or by blowing with low-pressure (5 to 10 psi) (34 to 70 kPa) dry, clean, compressed air.

NOTE 15: **Caution** — The air stream intensity should be established experimentally for each application.

8.8.3 *Aqueous Developers* — Aqueous developers should be applied to the part immediately after the excess penetrant has been removed and prior to drying. Aqueous developers should be prepared and maintained in accordance with the manufacturer's instructions and applied in such a manner as to ensure complete, even, part coverage. Caution should be exercised when using an aqueous developer with water-washable penetrants to avoid possible stripping of indications. Aqueous developers may be applied by spraying (see Note 17), flowing, or immersing the part. It is common to immerse the parts in a prepared developer bath. Immerse parts only long enough to coat all of the part surfaces with the developer (see Note 18). Then remove parts from the developer bath and allow to drain. Drain all excess developer from recesses and trapped sections to eliminate pooling of developer, which can obscure discontinuities. Dry the parts in accordance with 8.7. The dried developer coating appears as a translucent or white coating on the part.

NOTE 16: **Caution** — Atomized spraying is not recommended since a spotty film may result.

NOTE 17: **Caution** — If parts are left in the bath too long, indications may leach out.

8.8.4 *Nonaqueous Wet Developers* — After the excess penetrant has been removed and the surface has been dried, apply developer by spraying in such a manner as to ensure complete part coverage with a thin, even film of developer. These types of developer carrier evaporate very rapidly at normal room temperature and do not, therefore, require the use of a dryer (see Note 20). Dipping or flooding parts with nonaqueous developers is prohibited, since they may flush or dissolve the penetrant from within the discontinuities because of the solvent action of these types of developers.

NOTE 18: **Warning** — The vapors from the evaporating, volatile solvent developer carrier may be hazardous. Proper ventilation should be provided in all cases, but especially when the surface to be examined is inside a closed volume, such as a process drum or a small storage tank.

8.8.5 *Liquid Film Developers* — Apply by spraying as recommended by the manufacturer. Spray parts in such a manner as to ensure complete part coverage of the area being examined with a thin, even film of developer.

8.8.6 *Developing Time* — The length of time the developer is to remain on the part prior to examination should be not less than 10 min. Developing time begins immediately after the application of dry powder developer and as soon as the wet (aqueous and nonaqueous) developer coating is dry (that is, the solvent carrier has evaporated to dryness). The maximum permitted developing times are 2 h for aqueous developers and 1 h for nonaqueous developers.

8.9 *Examination* — Perform examination of parts after the applicable development time as specified in 8.8.6 to allow for bleedout of penetrant from discontinuities into the developer coating. It is good practice to observe the bleedout while applying the developer as an aid in interpreting and evaluating indications.

8.9.1 *Fluorescent Light Examination:*

8.9.1.1 *Visible Ambient Light Level* — Examine fluorescent penetrant indications under black light in a darkened area. Visible ambient light should not exceed 2 ft candles (20 Lx). The measurement should be made with a suitable photographic-type visible light meter on the surface being examined.

8.9.1.2 *Black Light Level Control* — Black light intensity, minimum of 1000 $\mu W/cm^2$, should be measured on the surface being examined, with a suitable black light meter. The black light wavelength shall be in the range of 320 to 380 nm. The intensity should be checked weekly to ensure the required output. Reflectors and filters should be checked daily for cleanliness and integrity. Cracked or broken ultraviolet (UV) filters should be replaced immediately. Defective bulbs, which radiate UV energy, must be replaced before further use. Since a drop in line voltage can cause decreased black light output with consequent inconsistent performance, a constant-voltage transformer should be used when there is evidence of voltage fluctuation.

Caution: Certain high-intensity black light may emit unacceptable amounts of visible light, which will cause fluorescent indications to disappear. Care should be taken to use only bulbs certified by the supplier to be suitable for such examination purposes.

NOTE 19: The recommended minimum light intensity in 8.9.1.2 is intended for general usage. For critical examinations, higher intensity levels may be required.

8.9.1.3 *Black Light Warm-Up* — Allow the black light to warm up for a minimum of 10 min prior to its use or measurement of the intensity of the ultraviolet light emitted.

8.9.1.4 *Visual Adaptation* — The examiner should be in the darkened area for at least 1 min before examining parts. Longer times may be necessary under some circumstances.

NOTE 20: **Caution** — Photochromic lenses shall not be worn during examination.

8.9.2 *Visible Light Examination:*

8.9.2.1 *Visible Light Level* — Visible penetrant indications can be examined in either natural or artificial light. Adequate illumination is required to ensure no loss in the sensitivity of the examination. A minimum light intensity at the examination site of 100 fc (1000 Lx) is recommended.

8.9.3 *Housekeeping* — Keep the examination area free of interfering debris, including fluorescent objects. Practice good housekeeping at all times.

8.9.4 *Evaluation* — Unless otherwise agreed, it is normal practice to interpret and evaluate the discontinuity based on the size of the indication (see Referenced Photographs E 433).

8.10 *Post Cleaning* — Post cleaning is necessary in those cases where residual penetrant or developer could interfere with subsequent processing or with service requirements. It is particularly important where residual penetrant examination materials might combine with other factors in service to produce corrosion. A suitable technique, such as a simple water rinse, waterspray, machine wash, vapor degreasing, solvent soak, or ultrasonic cleaning may be employed (see Annex on Post Cleaning). It is recommended that if developer removal is necessary, it should be carried out as promptly as possible after examination so that it does not "fix" on the part.

NOTE 21: **Caution** — Developers should be removed prior to vapor degreasing. Vapor degreasing can bake the developer on parts.

9. Special Requirements

9.1 *Impurities:*

9.1.1 When using penetrant materials on austenitic stainless steels, titanium, nickel-base or other high-temperature alloys, the need to restrict impurities such as sulfur, halogens and alkali metals must be considered. These impurities may cause embrittlement or corrosion, particularly at elevated temperatures. Any such evaluation should also include consideration of the form in which the impurities are present. Some penetrant materials contain significant amounts of these impurities in the form of volatile organic solvents. These normally evaporate quickly and usually do not cause problems. Other materials may contain impurities which are not volatile and may react with the part, particularly in the presence of moisture or elevated temperatures.

9.1.2 Because volatile solvents leave the surface quickly without reaction under normal examination procedures, penetrant materials are normally subjected to an evaporation procedure to remove the solvents before the materials are analyzed for impurities. The residue from this procedure is then analyzed in accordance with Test Method D 129, Test Method D 1552, or Test Method D 129 decomposition followed by Test Method D 516, Method B (Turbidimetric Method) for sulfur. The residue may also be analyzed by Test Method D 808 or Annex A2 on Methods for Measuring Total Chlorine Content in Combustible Liquid Penetrant Materials (for halogens other than fluorine) and Annex A3 on Method for Measuring Total Fluorine Content in Combustible Liquid Penetration Materials (for fluorine). An alternative procedure, Annex A4 on Determination of Anions by Ion Chromatography, provides a single instrumental technique for rapid sequential measurement of common anions such as chloride, fluoride, and sulfate. Alkali metals in the residue are determined by flame photometry or atomic absorption spectrophotometry.

NOTE 22: Some current standards indicate that impurity levels of sulfur and halogens exceeding 1% of any one suspect element may be considered excessive. However, this high a level may be unacceptable for some applications, so the actual maximum acceptable impurity level must be decided between supplier and user on a case by case basis.

9.2 *Evaluated-Temperature Examination* — Where penetrant examination is performed on parts that must be maintained at elevated temperature during examination, special materials and processing techniques may be required. Such examination requires qualification in accordance with 10.2. Manufacturer's recommendations should be observed.

10. Qualification and Requalification

10.1 *Personal Qualification* — When required by user/supplier agreement, all examination personnel shall be qualified/certified in accordance with a written procedure conforming to the applicable edition of recommended Practice SNT-TC-1A, ANSI/ASNT CP-189, NAS-410, or MIL-STD-410.

10.2 *Procedure Qualification* — Qualification of procedures using times or conditions differing from those specified or for new materials may be performed by any of

several methods and should be agreed by the contracting parties. A test piece containing one or more discontinuities of the smallest relevant size is used. The test piece may contain real or simulated discontinuities, providing it displays the characteristics of the discontinuities encountered in product examination.

10.3 *Nondestructive Testing Agency Qualification* — If a nondestructive testing agency as described in Practice E 543 is used to perform the examination, the agency shall meet the requirements of Practice E 543.

10.4 *Requalification* may be required when a change or substitution is made in the type of penetrant materials or in the procedure (see 10.2).

11. Keywords

11.1 fluorescent liquid penetrant testing; hydrophilic emulsification; lipophilic emulsification; liquid penetrant testing; nondestructive testing; solvent removable; visible liquid penetrant testing; water-washable methods

ANNEXES

(Mandatory Information)

A1. Cleaning of Parts and Materials

A1.1 Choice of Cleaning Method

A1.1.1 The choice of a suitable cleaning method is based on such factors as: (*1*) type of contaminant to be removed since no one method removes all contaminants equally well; (*2*) effect of the cleaning method on the parts; (*3*) practicality of the cleaning method for the part (for example, a large part cannot be put into a small degreaser or ultrasonic cleaner); and (*4*) specific cleaning requirements of the purchaser. The following cleaning methods are recommended:

A1.1.1.1 *Detergent Cleaning* — Detergent cleaners are nonflammable water-soluble compounds containing specially selected surfactants for wetting, penetrating, emulsifying, and saponifying various types of soils, such as grease and oily films, cutting and machining fluids, and unpigmented drawing compounds, etc. Detergent cleaners may be alkaline, neutral, or acidic in nature, but must be noncorrosive to the item being inspected. The cleaning properties of detergent solutions facilitate complete removal of soils and contamination from the surface and void areas, thus preparing them to absorb the penetrant. Cleaning time should average 10 to 15 min at 170 to 200°F (77 to 93°C) with moderate agitation, using concentrations (generally 6 to 8 oz/gal or 45 to 60 kg/m^3) recommended by the manufacturer of the cleaning compound.

A1.1.1.2 *Solvent Cleaning* — There are a variety of solvent cleaners that can be effectively utilized to dissolve such soils as grease and oily films, waxes and sealants, paints, and in general, organic matter. These solvents should be residue-free, especially when used as a hand-wipe solvent or as a dip-tank degreasing solvent. Solvent cleaners are not recommended for the removal of rust and scale, welding flux and spatter, and in general, inorganic soils. **Caution:** Some cleaning solvents are flammable and can be toxic. Observe all manufacturers' instructions and precautionary notes.

A1.1.1.3 *Vapor Degreasing* — Vapor degreasing is a preferred method of removing oil or grease-type soils from the surface of parts and from open discontinuities. It will not remove inorganic-type soils (dirt, corrosion, salts, etc.), and may not remove resinous soils (plastic coatings, varnish, paint, etc.). Because of the short contact time, degreasing may not completely clean out deep discontinuities and a subsequent solvent soak is recommended.

A1.1.1.4 *Alkaline Cleaning:*

(a) Alkaline cleaners are nonflammable water solutions containing specially selected detergents for wetting, penetrating, emulsifying, and saponifying various types of soils. Hot alkaline solutions are also used for rust removal and descaling to remove oxide scale which can mask surface discontinuities. Alkaline cleaner compounds must be used in accordance with the manufacturers' recommendations. **Caution:** Parts cleaned by the alkaline cleaning process must be rinsed completely free of cleaner and thoroughly dried by heat prior to the penetrant inspection process [part temperature at the time of penetrant application shall not exceed 125°F (52°C)].

(b) Steam cleaning is a modification of the hot-tank alkaline cleaning method, which can be used for preparation of large, unwieldy parts. It will remove inorganic soils and many organic soils from the surface of parts, but may not reach to the bottom of deep discontinuities, and a subsequent solvent soak is recommended.

A1.1.1.5 *Ultrasonic Cleaning* — This method adds ultrasonic agitation to solvent or detergent cleaning to improve cleaning efficiency and decrease cleaning time. It should be used with water and detergent if the soil to be removed is inorganic (rust, dirt, salts, corrosion products, etc.), and with organic solvent if the soil to be removed is organic (grease and oily films, etc.). After ultrasonic cleaning, parts should be heated to remove the cleaning fluid, then cooled to at least 125°F (52°C), before application of penetrant.

A1.1.1.6 *Paint Removal* — Paint films can be effectively removed by bond release solvent paint remover or disintegrating-type hot-tank alkaline paint strippers. In most cases, the paint film must be completely removed to expose the surface of the metal. Solvent-type paint removers can be of the high-viscosity thickened type for spray or brush application or can be of low viscosity two-layer type for dip-tank application. Both types of solvent paint removers are generally used at ambient temperatures, as received. Hot-tank alkaline strippers are water-soluble powder compounds generally used at 8 to 16 oz/gal (60 to 120 kg/m^3) of water at 180 to 200°F (82 to 93°C). After paint removal, the parts

must be thoroughly rinsed to remove all contamination from the void openings and then thoroughly dried.

A1.1.1.7 *Mechanical Cleaning and Surface Conditioning* — Metal-removing processes such as filing, buffing, scraping, mechanical milling, drilling, reaming, grinding, liquid honing, sanding, lathe cutting, tumble or vibratory deburring, and abrasive blasting, including abrasives such as glass beads, sand, aluminum oxide, ligno-cellulose pellets, metallic shot, etc., are often used to remove such soils as carbon, rust and scale, and foundry adhering sands, as well as to deburr or produce a desired cosmetic effect on the part. *These processes may decrease the effectiveness of the penetrant examination by smearing or peening over metal surfaces and filling discontinuities open to the surface, especially for soft metals such as aluminum, titanium, magnesium, and beryllium alloy.*

A1.1.1.8 *Acid Etching* — Inhibited acid solutions (pickling solutions) are routinely used for descaling part surfaces. Descaling is necessary to remove oxide scale, which can mask surface discontinuities and prevent penetrant from entering. Acid solutions/etchants are also used routinely to remove smeared metal that peens over surface discontinuities. Such etchants should be used in accordance with the manufacturers' recommendations. **Caution:**

NOTE A1: Etched parts and materials must be rinsed completely free of etchants, the surface neutralized and thoroughly dried by heat prior to application of penetrants. Acids and chromates can adversely affect the fluorescence of fluorescent materials.

NOTE A2 — Whenever there is a possibility of hydrogen embrittlement as a result of acid solution/etching, the part should be baked at a suitable temperature for an appropriate time to remove the hydrogen before further processing. After baking, the part shall be cooled to a temperature below 125°F (52°C) before applying penetrants.

A1.1.1.9 *Air Firing of Ceramics* — Heating of a ceramic part in a clean, oxidizing atmosphere is an effective way of removing moisture or light organic soil or both. The maximum temperature that will not cause degradation of the properties of the ceramic should be used.

A1.2 Post Cleaning

A1.2.1 *Removal of Developer* — Dry powder developer can be effectively removed with an air blow-off (free of oil) or it can be removed with water rinsing. Wet developer coatings can be removed effectively by water rinsing or water rinsing with detergent either by hand or with a mechanical assist (scrub brushing, washing machine, etc.). The soluble developer coatings simply dissolve off of the part with a water rinse.

A1.2.2 Residual penetrant may be removed through solvent action. Vapor degreasing (10 min minimum), solvent soaking (15 min minimum), and ultrasonic solvent cleaning (3 min minimum) techniques are recommended. In some cases, it is desirable to vapor degrease, then follow with a solvent soak. The actual time required in the vapor degreaser and solvent soak will depend on the nature of the part and should be determined experimentally.

A2. Methods for Measuring Total Chlorine Content in Combustible Liquid Penetrant Materials

A2.1 Scope and Application

A2.1.1 These methods cover the determination of chlorine in combustible liquid penetrant materials, liquid or solid. Its range of applicability is 0.001 to 5% using either of the alternative titrimetric procedures. The procedures assume that bromine or iodine will not be present. If these elements are present, they will be detected and reported as chlorine. The full amount of these elements will not be reported. Chromate interferes with the procedures, causing low or nonexistent end points. The method is applicable only to materials that are totally combustible.

A2.2 Summary of Methods

A2.2.1 The sample is oxidized by combustion in a bomb containing oxygen under pressure (**Caution,** see A2.2.1.1). The chlorine compounds thus liberated are absorbed in a sodium carbonate solution and the amount of chloride present is determined titrimetrically either against silver nitrate with the end point detected potiometrically (Method A) or coulometrically with the end point detected by current flow increase (Method B).

A2.2.1.1 *Safety* — Strict adherence to all of the provisions prescribed hereinafter ensures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least ½ in. (12.7 mm) thick, or equivalent protection be provided against unforeseeable contingencies.

A2.3 Apparatus

A2.3.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and leadwire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the chlorine content of the liquid in the bomb.

A2.3.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside and weighing 10 to 11 g, opaque fused silica, wide-form with an outside diameter of 29 mm at the top, a height of 19 mm, and a 5-mL capacity (Note 1), or nickel (Kawin capsule form), top diameter of 28 mm, 15 mm in height, and 5-mL capacity.

NOTE A2.1: Fused silica crucibles are much more economical and longer-lasting than platinum. After each use, they should be scrubbed out with fine, wet emery cloth, heated to dull red heat over a burner, soaked in hot water for 1 h, then dried and stored in a desiccator before reuse.

A2.3.3 *Firing Wire,* platinum, approximately No. 26 B & S gage.

A2.3.4 *Ignition Circuit* (Note A2.2), capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

NOTE A2.2: **Caution** — The switch in the ignition circuit shall be of a type that remains open, except when held in closed position by the operator.

A2.3.5 *Nylon Sewing Thread,* or *Cotton Wicking,* white.

A2.4 Purity of Reagents

A2.4.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

A2.4.2 Unless otherwise indicated, references to water shall be understood to mean referee grade reagent water conforming to Specification D 1193.

A2.5 Decomposition

A2.5.1 *Reagents and Materials:*

A2.5.1.1 *Oxygen,* free of combustible material and halogen compounds, available at a pressure of 40 atm (4.05 MPa).

A2.5.1.2 *Sodium Carbonate Solution (50 g Na_2CO_3/L)* — Dissolve 50 g of anhydrous Na_2CO_3 or 58.5 g of $Na_2CO_3 \cdot H_2O$) or 135 g of $Na_2CO_3 \cdot 10H_2O$ in water and dilute to 1 L.

A2.5.1.3 *White Oil,* refined.

A2.5.2 *Procedure:*

A2.5.2.1 *Preparation of Bomb and Sample* — Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Place 5 mL of Na_2CO_3 solution in the bomb (Note A2.3), place the cover on the bomb and vigorously shake for 15 s to distribute the solution over the inside of the bomb. Open the bomb, place the sample-filled sample cup in the terminal holder, and insert a short length of thread between the firing wire and sample. Use of a sample weight containing over 20 mg of chlorine may cause corrosion of the bomb. The sample weight should not exceed 0.4 g if the expected chlorine content is 2.5% or above. If the sample is solid, not more than 0.2 g should be used. Use 0.8 g of white oil with solid samples. If white oil will be used (Note A2.4), add it to the sample cup by means of a dropper at this time (**Caution,** see Notes A2.5 and A2.6).

NOTE A2.3: After repeated use of the bomb for chlorine determination, a film may be noticed on the inner surface. This dullness should be removed by periodic polishing of the bomb. A satisfactory method for doing this is to rotate the bomb in a lathe at about 300 rpm and polish the inside surface with Grit No. 2/0 or equivalent paper coated with a light machine oil to prevent cutting, and then with a paste of grit-free chromic oxide and water. This procedure will remove all but very deep pits and put a high polish on the surface. Before using the bomb, it should be washed with soap and water to remove oil or paste left from the polishing operation. Bombs with porous or pitted surfaces should never be used because of the tendency to retain chlorine from sample to sample. **Caution:** Do not use more than 1 g total of sample and white oil or other chlorine-free combustible material.

NOTE A2.4: If the sample is not readily miscible with white oil, some other nonvolatile, chlorine-free combustible diluent may be employed in place of white oil. However, the combined weight of sample and nonvolatile diluent shall not exceed 1 g. Some solid additives are relatively insoluble, but may be satisfactorily burned when covered with a layer of white oil.

NOTE A2.5: The practice of running alternately samples high and low in chlorine content should be avoided whenever possible. It is difficult to rinse the last traces of chlorine from the walls of the bomb and the tendency for residual chlorine to carry over from sample to sample has been observed in a number of laboratories. When a sample high in chlorine has preceded one low in chlorine content, the test on the low-chlorine sample should be repeated and one or both of the low values thus obtained should be considered suspect if they do not agree within the limits of repeatability of this method.

A2.5.2.2 *Addition of Oxygen* — Place the sample cup in position and arrange the nylon thread, or wisp of cotton so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen (**Caution,** Note A2.6) slowly (to avoid blowing the sample from the cup) until a pressure is reached as indicated in Table A2.1.

Note A2.6: **Caution** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

A2.5.2.3 *Combustion* — Immerse the bomb in a cold-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove

TABLE A2.1
GAGE PRESSURES

Capacity of Bomb, mL	Gage Pressure, atm (MPa) min[A]	max
300 to 350	38 (3.85)	40 (4.05)
350 to 400	35 (3.55)	37 (3.75)
400 to 450	30 (3.04)	32 (3.24)
450 to 500	27 (2.74)	29 (2.94)

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures present a safety requirement.

the bomb from the bath after immersion for at least ten minutes. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use (Note A2.3).

A2.6 Analysis, Method A, Potentiometric Titration Procedure

A2.6.1 *Apparatus:*

A2.6.1.1 *Silver Billet Electrode.*

A2.6.1.2 *Glass Electrode,* pH measurement type.

A2.6.1.3 *Buret,* 25-mL capacity, 0.05-mL graduations.

A2.6.1.4 *Millivolt Meter,* or expanded scale pH meter capable of measuring 0 to 220 mV.

Note A2.7: An automatic titrator is highly recommended in place of items A2.6.1.3 through A2.6.1.4. Repeatability and sensitivity of the method are much enhanced by the automatic equipment while much tedious effort is avoided.

A2.6.2 *Reagents and Materials:*

A2.6.2.1 *Acetone,* chlorine-free.

A2.6.2.2 *Methanol,* chlorine-free.

A2.6.2.3 *Silver Nitrate Solution (0.0282 N)* — Dissolve 4.7910 ± 0.0005 g of silver nitrate ($AgNO_3$) in water and dilute to 1 L.

A2.6.2.4 *Sodium Chloride Solution (0.0282 N)* — Dry a few grams of sodium chloride (NaCl) for 2 h at 130 to 150°C, weigh out 1.6480 ± 0.0005 g of the dried NaCl, dissolve in water, and dilute to 1 L.

A2.6.2.5 *Sulfuric Acid (1 + 2)* — Mix 1 volume of concentrated sulfuric acid (H_2SO_4, sp. gr 1.84) with 2 volumes of water.

A2.6.3 *Collection of Chlorine Solution* — Remove the sample cup with clean forceps and place in a 400-mL beaker. Wash down the walls of the bomb shell with a fine stream of methanol from a wash bottle, and pour the washings into the beaker. Rinse any residue into the beaker. Next, rinse the bomb cover and terminals into the beaker. Finally, rinse both inside and outside of the sample crucible into the beaker. Washings should equal but not exceed 100 mL. Add methanol to make 100 mL.

A2.6.4 *Determination of Chlorine* — Add 5 mL of H_2SO_4 (1:2) to acidify the solution (solution should be acid to litmus and clear of white Na_2CO_3 precipitate). Add 100 mL of acetone. Place the electrodes in the solution, start the stirrer (if mechanical stirrer is to be used), and begin titration. If titration is manual, set the pH meter on the expanded millivolt scale and note the reading. Add exactly 0.1 mL of $AgNO_3$ solution from the buret. Allow a few seconds stirring; then record the new millivolt reading. Subtract the second reading from the first. Continue the titration, noting each amount of $AgNO_3$ solution and the amount of difference between the present reading and the last reading. Continue adding 0.1-mL increments, making readings and determining differences between readings until a maximum difference between readings is obtained. The total amount of $AgNO_3$ solution required to produce this maximum differential is the end point. Automatic titrators continuously stir the sample, add titrant, measure the potential difference, calculate the differential, and plot the differential on a chart. The maximum differential is taken at the end point.

NOTE A2.8: For maximum sensitivity, 0.00282 *N* $AgNO_3$ solution may be used with the automatic titrator. This dilute reagent should not be used with large samples or where chlorine content may be over 0.1% since these tests will cause end points of 10 mL or higher. The large amount of water used in such titrations reduces the differential between readings, making the end point very difficult to detect. For chlorine contents over 1% in samples of 0.8 g or larger, 0.282 *N* $AgNO_3$ solution will be required to avoid exceeding the 10-mL water dilution limit.

A2.6.5 *Blank* — Make blank determinations with the amount of white oil used but omitting the sample. (Liquid samples normally require only 0.15 to 0.25 g of white oil while solids require 0.7 to 0.8 g.) Follow normal procedure, making two or three test runs to be sure the results are within the limits of repeatability for the test. Repeat this blank procedure whenever new batches of reagents or white oil are used. The purpose of the blank run is to measure the chlorine in the white oil, the reagents, and that introduced by contamination.

A2.6.6 *Standardization* — Silver nitrate solutions are not permanently stable, so the true activity should be checked when the solution is first made up and then periodically during the life of the solution. This is done by titration of a known NaCl solution as follows: Prepare a mixture of the amounts of the chemicals (Na_2CO_3 solution, H_2SO_4 solution, acetone, and methanol) specified

for the test. Pipet in 5.0 mL of 0.0282-*N* NaCl solution and titrate to the end point. Prepare and titrate a similar mixture of all the chemicals except the NaCl solution, thus obtaining a reagent blank reading. Calculate the normality of the $AgNO_3$ solution as follows:

$$N_{AgNO_3} = \frac{5.0 \times N_{NaCl}}{V_A - V_B}$$

where:

N_{AgNO_3} = normality of the $AgNO_3$ solution,
N_{NaCl} = normality of the NaCl solution,
V_A = millilitres of $AgNO_3$ solution used for the titration including the NaCl solution, and
V_B = millilitres of $AgNO_3$ solution used for the titration of the reagents only.

A2.6.7 *Calculation* — Calculate the chlorine content of the sample as follows:

$$\text{Chlorine, weight \%} = \frac{(V_S - V_B) \times N \times 3.545}{W}$$

where:

V_S = millilitres of $AgNO_3$ solution used by the sample,
V_B = millilitres of $AgNO_3$ solution used by the blank,
N = normality of the $AgNO_3$ solution, and
W = grams of sample used.

A2.6.8 *Precision and Accuracy:*

A2.6.8.1 The following criteria should be used for judging the acceptability of results:

A2.6.8.1.1 *Repeatability* — Results by the same analyst should not be considered suspect unless they differ by more than 0.006% or 10.5% of the value determined, whichever is higher.

A2.6.8.1.2 *Reproducibility* — Results by different laboratories should not be considered suspect unless they differ by more than 0.013% or 21.3% of the value detected, whichever is higher.

A2.6.8.1.3 *Accuracy* — The average recovery of the method is 86% to 89% of the actual amount present.

A2.7 Analysis, Method B, Coulometric Titration

A2.7.1 *Apparatus:*

A2.7.1.1 *Coulometric Chloride Titrator.*

A2.7.1.2 *Beakers,* two, 100-mL, or glazed crucibles (preferably with $1\frac{1}{2}$ in.-outside diameter bottom).

A2.7.1.3 *Refrigerator.*

A2.7.2 *Reagents:*

A2.7.2.1 *Acetic Acid, Glacial.*

A2.7.2.2 *Dry Gelatin Mixture.*

A2.7.2.3 *Nitric Acid.*

A2.7.2.4 *Sodium Chloride Solution* — 100 meq C/l. Dry a quantity of NaCl for 2 h at 130 to 150°C. Weigh out 5.8440 ± 0.0005 g of dried NaCl in a closed container, dissolve in water, and dilute to 1 L.

A2.7.3 *Reagent Preparation:*

NOTE A2.9: The normal reagent preparation process has been slightly changed, due to the interference from the 50 mL of water required to wash the bomb. This modified process eliminates the interference and does not alter the quality of the titration.

A2.7.3.1 *Gelatin Solution* — A typical preparation is: Add approximately 1 L or hot distilled or deionized water to the 6.2 g of dry gelatin mixture contained in one vial supplied by the equipment manufacturer. Gently heat with continuous mixing until the gelatin is completely dissolved.

A2.7.3.2 Divide into aliquots each sufficient for one day's analyses. (Thirty millilitres is enough for approximately eleven titrations.) Keep the remainder in a refrigerator, but do not freeze. The solution will keep for about 6 months in the refrigerator. When ready to use, immerse the day's aliquot in hot water to liquefy the gelatin.

A2.7.3.3 *Glacial Acetic Acid-Nitric Acid Solution* — A typical ratio is 12.5 to 1 (12.5 parts CH_3COOH to 1 part HNO_3).

A2.7.3.4 Mix enough gelatin solution and of acetic acid-nitric acid mixture for one titration. (A typical mixture is 2.5 mL of gelatin solution and 5.4 mL of acetic-nitric acid mixture.)

NOTE A2.10: The solution may be premixed in a larger quantity for convenience, but may not be useable after 24 h.

A2.7.3.5 Run at least three blank values and take an average according to the operating manual of the titrator. Determine separate blanks for both 5 drops of mineral oil and 20 drops of mineral oil.

A2.7.4 *Titration:*

A2.7.4.1 Weigh to the nearest 0.1 g and record the weight of the 100-mL beaker.

A2.7.4.2 Remove the sample crucible from the cover assembly support ring using a clean forceps, and, using a wash bottle, rinse both the inside and the outside with water into the 100-mL beaker.

A2.7.4.3 Empty the bomb shell into the 100-mL beaker. Wash down the sides of the bomb shell with water, using a wash bottle.

A2.7.4.4 Remove the cover assembly from the cover assembly support, and, using the wash bottle, rinse the under side, the platinum wire, and the terminals into the same 100-mL beaker. The total amount of washings should be 50 ± 1 g.

A2.7.4.5 Add specified amounts of gelatin mixture and acetic acid-nitric acid mixture, or gelatin mix-acetic acid-nitric acid mixture, if this was premixed, into the 100-mL beaker that contains the 50 g of washings including the decomposed sample.

A2.7.4.6 Titrate using a coulometric titrimeter, according to operating manual procedure.

A2.7.5 *Calculations* — Calculate the chloride ion concentration in the sample as follows:

$$\text{Chlorine, weight \%} = \frac{(P - B) \times M}{W}$$

where:

P = counter reading obtained with the sample,
B = average counter reading obtained with average of the three blank readings,
M = standardization constant. This is dependent on the instrument range setting in use and the reading obtained with a known amount of the 100 meq of Cl per litre of solution, and
W = weight of sample used, g.

A2.7.6 *Precision and Accuracy:*

A2.7.6.1 Duplicate results by the same operator can be expected to exhibit the following relative standard deviations:

Approximate % Chlorine	RSD, %
1.0 and above	0.10
0.1	2.5
0.003	5.9

A2.7.6.2 The method can be expected to report values that vary from the true value by the following amounts:

0.1% chlorine and above	±2%
0.001 to 0.01% chlorine	±9%.

A2.7.6.3 If bromine is present, 36.5% of the true amount will be reported. If iodine is present, 20.7% of the true amount will be reported. Fluorine will not be detected.

A3. Method for Measuring Total Fluorine Content in Combustible Liquid Penetrant Materials

A3.1 Scope and Application

A3.1.1 This method covers the determination of fluorine in combustible liquid penetrant materials, liquid or solid, that do not contain appreciable amounts of interfering elements, or have any insoluble residue after combustion. Its range of applicability is 1 to 200 000 ppm.

A3.1.2 The measure of the fluorine content employs the fluoride selective ion electrode.

A3.2 Summary of Method

A3.2.1 The sample is oxidized by combustion in a bomb containing oxygen under pressure (**Caution,** see A3.2.1.1). The fluorine compounds thus liberated are absorbed in a sodium citrate solution and the amount of fluorine present is determined potentiometrically through the use of a fluoride selective ion electrode.

A3.2.1.1 *Safety* — Strict adherence to all of the provisions prescribed hereinafter ensures against explosive rupture of the bomb, or a blow-out, provided the bomb is of proper design and construction and in good mechanical condition. It is desirable, however, that the bomb be enclosed in a shield of steel plate at least ½ in. (12.7 mm) thick, or equivalent protection be provided against unforeseeable contingencies.

A3.3 Interferences

A3.3.1 Silicon, calcium, aluminum, magnesium, and other metals forming precipitates with fluoride ion will interfere if they are present in sufficient concentration to exceed the solubility of their respective fluorides. Insoluble residue after combustion will entrain fluorine even if otherwise soluble.

A3.4 Apparatus

A3.4.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and leadwire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the fluorine content of the liquid in the bomb.

A3.4.2 *Sample Cup,* nickel, 20 mm in outside diameter at the bottom, 28 mm in outside diameter at the top, and 16 mm in height; or platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height, and weighing 10 to 11 g.

A3.4.3 *Firing Wire,* platinum, approximately No. 26 B & S gage.

A3.4.4 *Ignition Circuit* (Note A3.1), capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

NOTE A3.1: **Caution** — The switch in the ignition circuit shall be of a type that remains open, except when held in closed position by the operator.

A3.4.5 *Nylon Sewing Thread,* or *Cotton Wicking,* white.

A3.4.6 *Funnel,* polypropylene (Note A3.2).

A3.4.7 *Volumetric Flask,* polypropylene, 100-mL (Note A3.2).

A3.4.8 *Beaker,* polypropylene, 150-mL (Note A3.2).

A3.4.9 *Pipet,* 100-μL, Eppendorf-type (Note A3.2).

A3.4.10 *Magnetic Stirrer* and TFE-coated magnetic stirring bar.

A3.4.11 *Fluoride Specific Ion Electrode* and suitable reference electrode.

A3.4.12 *Millivolt Meter* capable of measuring to 0.1 mV.

NOTE A3.2: Glassware should never be used to handle a fluoride solution as it will remove fluoride ions from solution or on subsequent use carry fluoride ion from a concentrated solution to one more dilute.

A3.5 Reagents

A3.5.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

A3.5.2 *Purity of Water* — Unless otherwise indicated, all references to water shall be understood to mean Type I reagent water conforming to Specification D 1193.

A3.5.3 *Fluoride Solution, Stock (2000 ppm)* — Dissolve 4.4200 ± 0.0005 g of predried (at 130 to 150°C for 1 h, then cooled in a desiccator) sodium fluoride in distilled water and dilute to 1 L.

A3.5.4 *Oxygen,* free of combustible material and halogen compounds, available at a pressure of 40 atm (4.05 MPa).

A3.5.5 *Sodium Citrate Solution* — Dissolve 27 g of sodium citrate dihydrate in water and dilute to 1 L.

A3.5.6 *Sodium Hydroxide Solution (5 N)* — Dissolve 200 g of sodium hydroxide (NaOH) pellets in water and dilute to 1 L; store in a polyethylene container.

A3.5.7 *Wash Solution (Modified TISAB, Total Ionic Strength Adjustment Buffer)* — To 300 mL of distilled water, add 32 mL of glacial acetic acid, 6.6 g of sodium citrate dihydrate, and 32.15 g of sodium chloride. Stir to dissolve and then adjust the pH to 5.3 using 5 *N* NaOH solution. Cool and dilute to 1 L.

A3.5.8 *White Oil,* refined.

A3.6 Decomposition Procedure

A3.6.1 *Preparation of Bomb and Sample* — Cut a piece of firing wire approximately 100 mm in length.

TABLE A3.1
GAGE PRESSURES

Capacity of Bomb, mL	Gage Pressure, atm (MPa) min[A]	max
300 to 350	38	40
350 to 400	35	37
400 to 450	30	32
450 to 500	27	29

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures present a safety requirement.

Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Place 10 mL of sodium citrate solution in the bomb, place the cover on the bomb, and vigorously shake for 15 s to distribute the solution over the inside of the bomb. Open the bomb, place the sample-filled sample cup in the terminal holder, and insert a short length of thread between the firing wire and the sample. The sample weight used should not exceed 1 g. If the sample is a solid, add a few drops of white oil at this time to ensure ignition of the sample.

NOTE A3.3: Use of sample weights containing over 20 mg of chlorine may cause corrosion of the bomb. To avoid this it is recommended that for samples containing over 2% chlorine, the sample weight be based on the following table:

Chlorine Content, %	Sample weight, g	White Oil weight, g
2 to 5	0.4	0.4
5 to 10	0.2	0.6
10 to 20	0.1	0.7
20 to 50	0.05	0.7

Caution: Do not use more than 1 g total of sample and white oil or other fluorine-free combustible material.

A3.6.2 *Addition of Oxygen* — Place the sample cup in position and arrange the nylon thread, or wisp of cotton so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen (**Caution,** Note A3.4) slowly (to avoid blowing the sample from the cup) until a pressure is reached as indicated in Table A3.1.

NOTE A3.4: **Caution** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

A3.6.3 *Combustion* — Immerse the bomb in a cold-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the bomb from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the

bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use.

A3.6.4 *Collection of Fluorine Solution* — Remove the sample cup with clean forceps and rinse with wash solution into a 100-mL volumetric flask. Rinse the walls of the bomb shell with a fine stream of wash solution from a wash bottle, and add the washings to the flask. Next, rinse the bomb cover and terminals into the volumetric flask. Finally, add wash solution to bring the contents of the flask to the line.

A3.7 Procedure

A3.7.1 Ascertain the slope (millivolts per ten-fold change in concentration) of the electrode as described by the manufacturer.

A3.7.2 Obtain a blank solution by performing the procedure without a sample.

A3.7.3 Immerse the fluoride and reference electrodes in solutions and obtain the equilibrium reading to 0.1 mV. (The condition of the electrode determines the length of time necessary to reach equilibrium. This may be as little as 5 min or as much as 20 min.)

A3.7.4 Add 100 μL of stock fluoride solution and obtain the reading after the same length of time necessary for A3.7.3.

A3.8 Calculation

A3.8.1 Calculate the fluorine content of the sample as follows:

$$\text{Fluorine, ppm} = \frac{\left[\frac{2 \times 10^{-4}}{10\Delta E_1/S - 1} - \frac{2 \times 10^{-4}}{10\Delta E_2/S - 1}\right]}{W} \times 10^6$$

where:

ΔE_1 = millivolt change in sample solution on addition of 100 μL of stock fluoride solution,
ΔE_2 = millivolt change in blank solution on addition of 100 μL of the stock fluoride solution,
S = slope of fluoride electrode as determined in A3.7.1, and
W = grams of sample.

A3.9 Precision and Bias

A3.9.1 *Repeatability* — The results of two determinations by the same analyst should not be considered suspect unless they differ by more than 1.1 ppm (0.00011%) or 8.0% of the amount detected, whichever is greater.

A3.9.2 *Reproducibility* — The results of two determinations by different laboratories should not be considered suspect unless they differ by 6.7 ppm or 129.0% of the amount detected, whichever is greater.

A3.9.3 *Bias* — The average recovery of the method is 62 to 64% of the amount actually present although 83 to 85% recoveries can be expected with proper technique.

A4. Determination of Anions by Ion Chromatography With Conductivity Measurement

A4.1 Scope and Application

A4.1.1 This method is condensed from ASTM procedures and APHA Method 429 and optimized for the analysis of detrimental substances in organic based materials. It provides a single instrumental technique for rapid, sequential measurement of common anions such as bromide, chloride, fluoride, nitrate, nitrite, phosphate, and sulfate.

A4.2 Summary of Method

A4.2.1 The material must be put in the form of an aqueous solution before analysis can be attempted. The sample is oxidized by combustion in a bomb containing oxygen under pressure. The products liberated are absorbed in the eluant present in the bomb at the time of ignition. This solution is washed from the bomb, filtered, and diluted to a known volume.

A4.2.1.1 A filtered aliquot of sample is injected into a stream of carbonate-bicarbonate eluant and passed through a series of ion exchangers. The anions of interest are separated on the basis of their relative affinities for a low capacity, strongly basic anion exchanger (guard and separator column). The separated anions are directed onto a strongly acidic cation exchanger (suppressor column) where they are converted to their highly conductive acid form and the carbonate-bicarbonate eluant is converted to weakly conductive carbonic acid. The separated anions in their acid form are measured by conductivity. They are identified on the basis of retention time as compared to standards. Quantitation is by measurement of peak area or peak height. Blanks are prepared and analyzed in a similar fashion.

A4.2.2 *Interferences* — Any substance that has a retention time coinciding with that of any anion to be determined will interfere. For example, relatively high concentrations of low-molecular-weight organic acids interfere with the determination of chloride and fluoride. A high concentration of any one ion also interferes with the resolution of others. Sample dilution overcomes many interferences. To resolve uncertainties of identification or quantitation use the method of known additions. Spurious peaks may result from contaminants in reagent water, glassware, or sample processing apparatus. Because small sample volumes are used, scrupulously avoid contamination.

A4.2.3 *Minimum Detectable Concentration* — The minimum detectable concentration of an anion is a function of sample size and conductivity scale used. Generally, minimum detectable concentrations are in the range of 0.05 mg/L for F^- and 0.1 mg/L for Br^-, Cl^-, NO_3^-, NO_2^-, PO_4^{3-}, and SO_4^{2-} with a 100-µL sample loop and a 10-µmho full-scale setting on the conductivity detector. Similar values may be achieved by using a higher scale setting and an electronic integrator.

A4.3 Apparatus

A4.3.1 *Bomb,* having a capacity of not less than 300 mL, so constructed that it will not leak during the test, and that quantitative recovery of the liquids from the bomb may be readily achieved. The inner surface of the bomb may be made of stainless steel or any other material that will not be affected by the combustion process or products. Materials used in the bomb assembly, such as the head gasket and leadwire insulation, shall be resistant to heat and chemical action, and shall not undergo any reaction that will affect the chlorine content of the liquid in the bomb.

A4.3.2 *Sample Cup,* platinum, 24 mm in outside diameter at the bottom, 27 mm in outside diameter at the top, 12 mm in height outside, and weighing 10 to 11 g; opaque fused silica, wide-form with an outside diameter of 29 mm at the top, a height of 19 mm, and a 5-mL capacity (Note A4.1), or nickel (Kawin capsule form), top diameter of 28 mm, 15 mm in height, and 5-mL capacity.

NOTE A4.1: Fused silica crucibles are much more economical and longer lasting than platinum. After each use, they should be scrubbed out with fine, wet emery cloth, heated to dull red heat over a burner, soaked in hot water for 1 h then dried and stored in a desiccator before reuse.

A4.3.3 *Firing Wire,* platinum, approximately No. 26 B and S gage.

A4.3.4 *Ignition Circuit* (Note A4.2), capable of supplying sufficient current to ignite the nylon thread or cotton wicking without melting the wire.

NOTE A4.2: **Caution** — The switch in the ignition circuit shall be of a type that remains open, except when held in closed position by the operator.

A4.3.5 *Nylon Sewing Thread,* or *Cotton Wicking,* white.

A4.3.6 *Ion Chromatograph,* including an injection valve, a sample loop, guard, separator, and suppressor columns, a temperature-compensated small-volume conductivity cell (6 µL or less), and a strip chart recorder capable of full-scale response of 2 s or less. An electronic peak integrator is optional. The ion chromatograph shall be capable of delivering 2 to 5 mL eluant/ min at a pressure of 1400 to 6900 kPa.

A4.3.7 *Anion Separator Column,* with styrene divinyl-benzene-based low-capacity pellicular anion-exchange resin capable of resolving Br^-, Cl^-, F^-, NO_3^-, NO_2^-, PO_4^{3-}, and SO_4^{2-}; 4 × 250 mm.

A4.3.8 *Guard Column,* identical to separator column except 4 × 50 mm, to protect separator column from fouling by particulates or organics.

A4.3.9 *Suppressor Column,* high-capacity cation-exchange resin capable of converting eluant and separated anions to their acid forms.

A4.3.10 *Syringe,* minimum capacity of 2 mL and equipped with a male pressure fitting.

A4.4 Reagents

A4.4.1 *Purity of Reagents* — Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent has sufficiently high purity to permit its use without lessening the accuracy of the determination.

A4.4.2 *Deionized or Distilled Water,* free from interferences at the minimum detection limit of each constituent and filtered through a 0.2-µm membrane filter to avoid plugging columns.

A4.4.3 *Eluant Solution,* sodium bicarbonate-sodium carbonate, 0.003M $NaHCO_3$– 0.0024M Na_2CO_3: dissolve 1.008 g $NaHCO_3$ and 1.0176 g Na_2CO_3 in water and dilute to 4 L.

A4.4.4 *Regenerant Solution 1,* H_2SO_4, 1 N, use this regenerant when suppressor is not a continuously regenerated one.

A4.4.5 *Regenerant Solution 2,* H_2SO_4, 0.025 N, dilute 2.8 mL conc H_2SO_4 to 4 L or 100 mL regenerant solution 1 to 4 L. Use this regenerant with continuous regeneration fiber suppressor system.

A4.4.6 *Standard Anion Solutions,* 100 mg/L, prepare a series of standard anion solutions by weighing the indicated amount of salt, dried to a constant weight at 105°C, to 1000 mL. Store in plastic bottles in a refrigerator; these solutions are stable for at least one month.

Anion	Salt	Amount, g/L
Cl^-	NaCl	1.6485
F^-	NaF	2.2100
Br^-	NaBr	1.2876
NO_3^-	$NaNO_3$	1.3707
NO_2^-	$NaNO_2$	1.4998
PO_4^{3-}	KH_2PO_4	1.4330
SO_4^{2-}	K_2SO_4	1.8141

A4.4.7 *Combined Working Standard Solution, High Range* — Combine 10 mL of the Cl^-, F^-, NO_3^-, NO_2^-, and PO_4^{3-} standard anion solutions, 1 mL of the Br^-, and 100 mL of the SO_4^{2-} standard solutions, dilute to 1000 mL, and store in a plastic bottle protected from light; contains 10 mg/L each of Cl^-, F^-, NO_3^-, NO_2^-, and PO_4^{3-}, 1 mg Br^-/L, and 100 mg SO_4^{2-}/L. Prepare fresh daily.

A4.4.8 *Combined Working Standard Solution, Low Range* — Dilute 100 mL combined working standard solution, high range, to 1000 mL and store in a plastic bottle protected from light; contains 1.0 mg/L each Cl^-, F^-, NO_3^-, NO_2^-, and PO_4^{3-}, 0.1 mg Br^-/L, and 10 mg SO_4^{2-}/L. Prepare fresh daily.

A4.4.9 *Alternative Combined Working Standard Solutions* — Prepare appropriate combinations according to anion concentration to be determined. If NO_2^- and PO_4^{3-} are not included, the combined working standard is stable for one month.

A4.5 *Decomposition Procedure*

A4.5.1 *Preparation of Bomb and Sample* — Cut a piece of firing wire approximately 100 mm in length. Coil the middle section (about 20 mm) and attach the free ends to the terminals. Arrange the coil so that it will be above and to one side of the sample cup. Place 5 mL of Na_2CO_3/$NaHCO_3$ solution in the bomb, place the cover on the bomb, and vigorously shake for 15 s to distribute the solution over the inside of the bomb. Open the bomb, place the sample-filled sample cup in the terminal holder, and insert a short length of thread between the firing wire and the sample. The sample weight used should not exceed 1 g. If the sample is a solid, add a few drops of white oil at this time to ensure ignition of the sample.

NOTE A4.3: Use of sample weights containing over 20 mg of chlorine may cause corrosion of the bomb. To avoid this it is recommended that for samples containing over 2% chlorine, the sample weight be based on the following:

Chlorine content, %	Sample weight, g	White Oil weight, g
2 to 5	0.4	0.4
5 to 10	0.2	0.6
10 to 20	0.1	0.7
20 to 50	0.05	0.7

CAUTION: Do not use more than 1 g total of sample and white oil or other fluorine-free combustible material.

A4.5.2 *Addition of Oxygen* — Place the sample cup in position and arrange the nylon thread, or wisp of cotton so that the end dips into the sample. Assemble the bomb and tighten the cover securely. Admit oxygen (**Caution,** Note A4.4) slowly (to avoid blowing the sample from the cup) until a pressure is reached as indicated in Table A4.1.

NOTE A4.4: **Caution** — Do not add oxygen or ignite the sample if the bomb has been jarred, dropped, or tilted.

TABLE A4.1
GAGE PRESSURES

Capacity of Bomb, mL	Gage Pressures, atm min[A]	Gage Pressures, atm max
300 to 350	38	40
350 to 400	35	37
400 to 450	30	32
450 to 500	27	29

[A] The minimum pressures are specified to provide sufficient oxygen for complete combustion and the maximum pressures present a safety requirement.

A4.5.3 *Combustion* — Immerse the bomb in a cold-water bath. Connect the terminals to the open electrical circuit. Close the circuit to ignite the sample. Remove the bomb from the bath after immersion for at least 10 min. Release the pressure at a slow, uniform rate such that the operation requires not less than 1 min. Open the bomb and examine the contents. If traces of unburned oil or sooty deposits are found, discard the determination, and thoroughly clean the bomb before again putting it in use.

A4.5.4 *Collection of Solution* — Remove the sample cup with clean forceps and rinse with deionized water and filter the washings into a 100-mL volumetric flask. Rinse the walls of the bomb shell with a fine stream of deionized water from a wash bottle, and add the washings through the filter paper to the flask. Next, rinse the bomb cover and terminals and add the washings through the filter into the volumetric flask. Finally, add deionized water to bring the contents of the flask to the line. Use aliquots of this solution for the ion chromatography (IC) analysis.

A4.6 Procedure

A4.6.1 *System Equilibration* — Turn on ion chromatograph and adjust eluant flow rate to approximate the separation achieved in Fig. A4.1 (2 to 3 mL/min). Adjust detector to desired setting (usually 10 μmho) and let system come to equilibrium (15 to 20 min). A stable base line indicates equilibrium conditions. Adjust detector offset to zero-out eluant conductivity; with the fiber suppressor adjust the regeneration flow rate to maintain stability, usually 2.5 to 3 mL/min.

A4.6.1.1 Set up the ion chromatograph in accordance with the manufacturer's instructions.

A4.6.2 *Calibration* — Inject standards containing a single anion or a mixture and determine approximate retention times. Observed times vary with conditions but if standard eluant and anion separator column are used, retention always in the order F^-, Cl^-, NO_2^-, PO_4^{3-}, Br^-,

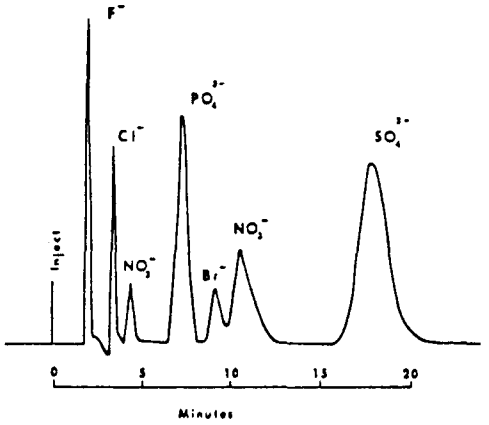


FIG. A4.1 TYPICAL ANION PROFILE

NO_3^-, and SO_4^{2-}. Inject at least three different concentrations for each anion to be measured and construct a calibration curve by plotting peak height or area against concentration on linear graph paper. Recalibrate whenever the detector setting is changed. With a system requiring suppressor regeneration, NO_2^- interaction with the suppressor may lead to erroneous NO_2^- results; make this determination only when the suppressor is at the same stage of exhaustion as during standardization or recalibrate frequently. In this type of system the water dip (see Note A4.4) may shift slightly during suppressor exhaustion and with a fast run column this may lead to slight interference for F^- or Cl^-. To eliminate this interference, analyze standards that bracket the expected result or eliminate the water dip by diluting the sample with eluant or by adding concentrated eluant to the sample to give the same HCO_3^-/CO_3^{2-} concentration as in the eluant. If sample adjustments are made, adjust standards and blanks identically.

NOTE A4.5: Water dip occurs because water conductivity in sample is less than eluant conductivity (eluant is diluted by water).

A4.6.2.1 If linearity is established for a given detector setting, it is acceptable to calibrate with a single standard. Record the peak height or area and retention time to permit calculation of the calibration factor, F.

A4.6.3 *Sample Analysis* — Remove sample particulates, if necessary, by filtering through a prewashed 0.2-μm-porediam membrane filter. Using a prewashed syringe of 1 to 10 mL capacity equipped with a male luer fitting inject sample or standard. Inject enough sample to flush sample loop several times: for 0.1 mL sample loop inject at least 1 mL. Switch ion chromatograph from load to inject mode and record peak heights and retention times on strip chart recorder. After the last peak (SO_4^{2-}) has appeared and the conductivity signal has returned to base line, another sample can be injected.

TABLE A4.2
PRECISION AND ACCURACY OBSERVED FOR ANIONS AT VARIOUS CONCENTRATION LEVELS IN REAGENT WATER

Anion	Amount Added, mg/L	Amount Found, mg/L	Overall Precision, mg/L	Single-Operator Precision, mg/L	Significant Bias 95% Level
F^-	0.48	0.49	0.05	0.03	No
F^-	4.84	4.64	0.52	0.46	No
Cl	0.76	0.86	0.38	0.11	No
Cl^-	17	17.2	0.82	0.43	No
Cl	455	471	46	13	No
NO_2	0.45	0.09	0.09	0.04	Yes, neg
NO_2	21.8	19.4	1.9	1.3	Yes, neg
Br^-	0.25	0.25	0.04	0.02	No
Br^-	13.7	12.9	1.0	0.6	No
PO_4^{3-}	0.18	0.10	0.06	0.03	Yes, neg
PO_4^{3-}	0.49	0.34	0.15	0.17	Yes, neg
NO_3^-	0.50	0.33	0.16	0.03	No
NO_3^-	15.1	14.8	1.15	0.9	No
SO_4^{2-}	0.51	0.52	0.07	0.03	No
SO_4^{2-}	43.7	43.5	2.5	2.2	No

A4.6.4 *Regeneration* — For systems without fiber suppressor regenerate with 1 N H_2SO_4 in accordance with the manufacturer's instructions when the conductivity base line exceeds 300 μmho when the suppressor column is on line.

A4.7 Calculation

A4.7.1 Calculate concentration of each anion, in mg/L, by referring to the appropriate calibration curve. Alternatively, when the response is shown to be linear, use the following equation:

$$C = H \times F \times D$$

where:

C = mg anion/L,
H = peak height or area,
F = response factor – concentration of standard/height (or area) of standard, and
D = dilution factor for those samples requiring dilution.

A4.8 Precision and Bias

A4.8.1 Samples of reagent water to which were added the common anions were analyzed in 15 laboratories with the results shown in Table A4.2.

ARTICLE 25
MAGNETIC PARTICLE STANDARDS

STANDARD TEST METHODS FOR NONDESTRUCTIVE MEASUREMENT OF DRY FILM THICKNESS OF NONMAGNETIC COATINGS APPLIED TO A FERROUS BASE

SD-1186

(Identical with ASTM D 1186-01)

1. Scope

1.1 These test methods cover the nondestructive measurement of the dry film thickness of nonmagnetic coatings applied over a ferrous base material using commercially available test instruments. The test methods are intended to supplement manufacturers' instructions for the manual operation of the gages and are not intended to replace them. They cover the use of instruments based on magnetic measuring principles only. Test Method A provides for the measurement of films using mechanical magnetic pull-off gages and Test Method B provides for the measurement of films using magnetic electronic gages.

1.2 These test methods are not applicable to coatings that will be readily deformable under the load of the measuring instruments, as the instrument probe must be placed directly on the coating surface to take a reading.

1.3 The values given in SI units of measurement are to be regarded as the standard. The values in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products

D 823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels

2.2 *Steel Structures Painting Council Standard:*

SSPC-PA2 Measurement of Dry Paint Thickness with Magnetic Gages

TEST METHOD A—MAGNETIC PULL-OFF GAGES

3. Summary of Test Method

3.1 Instruments complying with this test method measure thickness by using a spring calibrated to determine the force required to pull a magnet from a ferrous base

coated with a nonmagnetic film. The instrument must be placed directly on the coating surface to take a reading.

3.2 The attractive force of the magnet to the substrate varies inversely with the thickness of the applied film. The spring tension required to overcome the attraction of the magnet to the substrate is shown on the instrument scale as the distance (in mils or microns) between the magnet and the substrate.

4. Significance and Use

4.1 Many coating properties are markedly affected by the thickness of the dry film such as adhesion, corrosion protection, flexibility, and hardness. To be able to compare results obtained by different operators, it is essential to know film thickness.

4.2 Most protective and high performance coatings are applied to meet a requirement or a specification for the dry-film thickness of each coat, or for the complete system, or both. Coatings must be applied within certain minimum and maximum thicknesses to fill their expected function. In addition to potential performance deficiencies, it is uneconomical to apply more material than necessary when coating large areas. This test method is used to measure film thickness of coatings on ferrous metals.

5. Apparatus

5.1 *Permanent Magnet,* small, either attached directly to a coil spring ("pencil" gage) or to a horizontal lever arm that is attached to a helical spring ("dial-type" gage). Increasing force is applied to the magnet by extending the coil spring in the first case or turning a graduated dial that coils the helical spring in the second. The readings obtained are shown directly on the instrument scale.

5.2 *Coating Thickness Standards,* with assigned values traceable to national standards are available from several sources, including most manufacturers of coating thickness gages.

6. Test Specimens

6.1 When this test method is used in the field, the specimen is the coated structure or article on which the thickness is to be evaluated.

6.2 For laboratory use, apply the material to be tested to panels of similar roughness, shape, thickness, composition and magnetic properties on which it is desired to determine the thickness.

NOTE 1 — Applicable test panel description and surface preparation methods are given in Practice D 609.

NOTE 2 — Coatings should be applied in accordance with Practices D 823 or as agreed upon between the contracting parties.

7. Verification of Calibration of Apparatus

7.1 Different gage manufacturers follow different methods of calibration adjustment. Verify calibration according to manufacturer's instructions.

7.2 The section of the type of standards used to verify calibration should be predicated upon which type provides the best and most appropriate calibration considering: type of gage, sample surface geometry, and contract requirements. Appendix X1 provides information helpful to making an informed selection of standards.

7.3 Following the manufacturer's operating instructions, measure the thickness of a series of calibration standards covering the expected range of coating thickness. To guard against measuring with an inaccurate gage, recheck the gage at regular intervals. That interval should be set by agreement between contracting parties and maintained throughout the control process.

NOTE 3 — Generally "Dial-type" instruments can be used in any position, while "pencil-type" instruments may be used in the vertical position only unless they have separate indicators for the horizontal and vertical positions. Follow the manufacturer's recommendations.

8. Procedure

8.1 Use the instrument only after calibration has been verified in accordance with Section 7.

8.2 Ensure that the coating is dry prior to use of the instrument.

8.3 Inspect the probe tip and surface to be measured to ensure that they are clean. Adherent magnetic filings or other surface contaminants will affect gage readings.

8.4 Take readings in locations free of electrical or magnetic fields. The location should also be free of vibration when using mechanical magnetic pull-off instruments.

8.5 The accuracy of the measurement can be influenced when made within 25 mm (1 in.) of the edge or right angle in the sample.

8.6 Measure the coating, following the manufacturer's instructions.

8.7 Verify calibration periodically to ensure that the instrument continues to read properly. If the instrument is found to be out of adjustment, remeasure the thicknesses taken since the last satisfactory calibration check was made.

8.8 Take a sufficient number of readings to characterize the surface.

8.8.1 For laboratory measurements, a recommended minimum is three for a 75 by 150- mm (3 by 6-in.) panel and more in proportion to size.

8.8.2 For field measurements, a recommended minimum is five determinations at random for every 10 m^2(100 ft^2) of surface area. Each of the five determinations should be the mean of three separate gage readings within the area of a 4-cm (1.5-in.) diameter circle.

8.9 Make measurements at least 13 mm (½ in.) away from any edge or corner of the specimen. If it is necessary to measure closer than 13 mm (½ in.), verify the effect (if any), the edge has on the mesurement.

NOTE 4 — or additional information describing the number of measurements to be taken on large structures, and on non-smooth surfaces, refer to SSPC PA-2.

9. Report

9.1 Report the following information:

9.1.1 Instrument used, serial number,

9.1.2 Range, and mean of the thickness readings, and

9.1.3 Depending upon the application, record the individual readings as well.

10. Precision and Bias

10.1 A new round-robin study was performed recently. Data are being analyzed statistically. When completed, the required "Repeatability and Repoducibility" sections of this test method will be written and the round-robin study documented in an ASTM research report.

10.2 *Bias* — The bias for Test Method A of this standard for measuring dry film thickness cannot be determined because each instrument has its own bias.

TEST METHOD B — ELECTRONIC GAGES

11. Summary of Test Method

11.1 Instruments complying with this test method measure thicknesses by placing a probe on the coated surface and use electronic circuitry to convert a reference signal into coating thickness.

11.2 Instruments of this type determine, within the probe or the instrument itself, changes in the magnitic flux caused by variations in the distance between the probe and the substrate.

12. Apparatus

12.1 The testing apparatus shall be an electrically operated instrument utilizing a probe that houses a permanent magnet or coil energized by alternating current that is placed directly on the surface. The coating thickness is shown on the instrument's display.

12.2 Coating thickness standards with assigned values traceable to national standards are available.

13. Test Specimens

13.1 See Section 6.

14. Calibration of Apparatus

14.1 See Section 7.

15. Procedure

15.1 See Section 8. Exclude steps 8.5 and 8.7.

16. Report

16.1 See Section 9.

17. Precision and Bias

17.1 *Precision* — See Section 10.

17.2 *Bias* — The bias for Test Method B of this standard for measuring dry film thickness cannot be determined because each instrument has its own bias.

18. Keywords

18.1 coating thickness; dry film thickness; magnetic gages; nondestructive thickness; paint thickness

APPENDIX

(Nonmandatory Information)

X1. CHARACTERISTICS AFFECTING GAGE READINGS

X1.1 It is always good practice to ensure the reliability of gage readings by performing a verification test periodically, either before or after critical determinations. This practice ensures that, not only is the gage reading correctly, but also that it is correctly calibrated to provide maximum accuracy of readings on the sample. Not all applications require this level of certainty so, while suggested, the inclusion of this practice is up to the contacting individuals to decide on implementation.

X1.2 Certain characteristics of samples may affect the accuracy of the calibrations. These include, but may not be limited to:

X1.2.1 Surface profile of the substrate (roughness),

X1.2.2 Surface profile of the coating,

X1.2.3 Thickness of the substrate,

X1.2.4 Geography of the sample surface (curves with small radii, small diameters, complex curves, etc.), and

X1.2.5 Any characteristic that affects the magnetic or eddy current permeability of the substrate or coating, such as residual magnetism, or lack of homogeneity of magnetic characteristics.

X1.3 Calibration done on smooth, polished standards ensure that a gage can be properly calibrated, and that calibration is appropriate for any measurements on samples of the same characteristics, but it may not be the best for measurements of samples that differ from the calibration materials. When possible, verification should be done on samples of known thickness of coating applied to substrates as similar as possible to the sample to be tested.

X1.4 It is not practical to provide known thickness standards for all possible sample configurations. An alternative method is to verify calibration on a bare substrate as similar as possible to the sample, using a nonmagnetic metal foil, plastic shim or film of known thickness to simulate a coating.

X1.5 In using this verification of calibration method, it is necessary to be aware of additional characteristics that can affect the measured values. Plastic or brass shim stock typically has an inherent curve. This curve can act as a leaf spring and cause a magnetic pull- off gage to be "pushed" off the surface prematurely, resulting in an incorrect reading.

X1.6 With some materials and thickness, it is possible that the shim will not lie flat, which will also cause an erroneous reading. Various techniques exist to minimize this effect, such as mounting the shim in a holder that maintains tension on the shim to eliminate the tendency of the shim to curve.

X1.7 Other factors experienced with plastic shims, which are not usually present with painted or plated calibration standards include (but are not limited to):

X1.7.1 Permanent creases in the shim due to folding,

X1.7.2 Air entrapment between the shim and substrate,

X1.7.3 Distortion due to environmental conditions, such as temperature, and

X1.7.4 Shim thickness inconsistency due to the pressure of the probe tip. This may be a permanent "dimple" in the shim.

X1.8 Even with these factors affecting potential accuracy of plastic shims, in many applications, verification of calibration using plastic shims on the sample to be measured, can be a more appropriate (accurate) calibration than using plated or painted standards.

X1.9 No matter what standards are used, they should be periodically verified to ensure the assigned value is correct. Even metal coated on metal can wear or be damaged to an extent that readings are affected.

STANDARD GUIDE FOR MAGNETIC PARTICLE EXAMINATION

SE-709

(Identical with ASTM Specification E 709-95)

1. Scope

1.1 This guide describes techniques for both dry and wet magnetic particle examination, a nondestructive method for detecting cracks and other discontinuities at or near the surface in ferromagnetic materials. Magnetic particle examination may be applied to raw material, semifinished material (billets, blooms, castings, and forgings), finished material and welds, regardless of heat treatment or lack thereof. It is useful for preventive maintenance examination.

1.1.1 This guide is intended as a reference to aid in the preparation of specifications/standards, procedures and techniques.

1.2 This guide is also a reference that may be used as follows:

1.2.1 To establish a means by which magnetic particle examination procedures recommended or required by individual organizations can be reviewed to evaluate their applicability and completeness.

1.2.2 To aid in the organization of the facilities and personnel concerned in magnetic particle examination.

1.2.3 To aid in the preparation of procedures dealing with the examination of materials and parts. This guide describes magnetic particle examination techniques that are recommended for a great variety of sizes and shapes of ferromagnetic materials and widely varying examination requirements. Since there are many acceptable differences in both procedure and technique, the explicit requirements should be covered by a written procedure (see Section 21).

1.3 This guide does not indicate, suggest, or specify acceptance standards for parts/pieces examined by these techniques. It should be pointed out, however, that after indications have been produced, they must be interpreted or classified and then evaluated. For this purpose there should be a separate code, specification, or a specific agreement to define the type, size, location, degree of alignment and spacing, area concentration, and orientation of indications that are unacceptable in a specific part versus those which need not be removed before part acceptance. Conditions where rework or repair are not permitted should be specified.

1.4 This guide describes the use of the following magnetic particle method techniques.

1.4.1 Dry magnetic powder (see 8.3),

1.4.2 Wet magnetic particle (see 8.4),

1.4.3 Magnetic slurry/paint magnetic particle (see 8.4.8), and

1.4.4 Polymer magnetic particle (see 8.4.8).

1.5 *Personnel Qualification* — Personnel performing examination to this guide shall be qualified and certified in accordance with ASNT Qualification and Certification of NDT Personnel, or SNT-TC-1A, or MIL-STD-410 for military purposes, or as specified in the contract or purchase order.

1.6 *Nondestructive Testing Agency* — If a nondestructive testing agency as described in Practice E 543 is used to perform the examination, the testing agency shall meet the requirements of Practice E 543.

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1.8 The numerical values shown in inch-pound units are to be regarded as the standard. SI units are provided for information only.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 93 Test Methods for Flash Point by Pensky-Martens Closed Tester

D 96 Test Methods for Water and Sediment in Crude Oil by Centrifuge Method (Field Procedure)

D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)

D 445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)

D 808 Test Method for Chlorine in New and Used Petroleum Products (Bomb Method)

E 165 Test Method for Liquid Penetrant Examination

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *Society of Automotive Engineers (SAE): Aerospace Materials Specifications:*

AMS 2641 Vehicle Magnetic Particle Inspection

2.3 *American Society for Nondestructive Testing:*

SNT-TC-1A Recommended Practice Magnetic Particle Method

ASNT Qualification and Certification of NDT Personnel

2.4 *U.S. Government Publications:*

FED-STD 313 Material Safety Data Sheets Preparation and the Submission of

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

MIL-STD-1949 Magnetic Particle Inspection, Method of

2.5 *OSHA Document:*

29CFR 1910.1200 Hazard Communication

3. Terminology

3.1 For definitions of terms used in the practice, refer to Terminology E 1316.

4. Summary of Guide

4.1 *Principle* — The magnetic particle method is based on the principle that magnetic field lines when present in a ferromagnetic material, will be distorted by a change in material continuity, such as a sharp dimensional change or a discontinuity. If the discontinuity is open to or close to the surface of a magnetized material, flux lines will be distorted at the surface, a condition termed as "flux leakage." When fine magnetic particles are distributed over the area of the discontinuity while the flux leakage exists, they will be held in place and the accumulation of particles will be visible under the proper lighting conditions. While there are variations in the magnetic particle method, they all are dependent on this principle, that magnetic particles will be retained at the locations of magnetic flux leakage.

4.2 *Method* — While this practice permits and describes many variables in equipment, materials, and procedures, there are three steps essential to the method:

4.2.1 The part must be magnetized.

4.2.2 Magnetic particles of the type designated in the contract/purchase order/specification must be applied while the part is magnetized.

4.2.3 Any accumulation of magnetic particles must be observed, interpreted, and evaluated.

4.3 *Magnetization:*

4.3.1 *Ways to Magnetize* — A ferromagnetic material can be magnetized either by passing an electric current through the material or by placing the material within a magnetic field originated by an external source. The entire mass or a portion of the mass can be magnetized as dictated by size and equipment capacity or need. As previously noted, the discontinuity must interrupt the normal path of the magnetic field lines. If a discontinuity is open to the surface, the flux leakage will be at the maximum for that particular discontinuity. When that same discontinuity is below the surface, flux leakage evident on the surface will be less. Practically, discontinuities must be open to the surface, to create sufficient flux leakage to accumulate magnetic particles.

4.3.2 *Field Direction* — If a discontinuity is oriented parallel to the magnetic field lines, it may be essentially undetectable. Therefore, since discontinuities may occur in any orientation, it may be necessary to magnetize the part or area of interest twice or more sequentially in different directions by the same method or a combination of methods (see Section 13) to induce magnetic field lines in a suitable direction in order to perform an adequate examination.

4.3.3 *Field Strength* — The magnetic field must be of sufficient strength to indicate those discontinuities which are unacceptable, yet must not be so strong that an excess of particles is accumulated locally thereby masking relevant indications (see Section 14).

4.4 *Types of Magnetic Particles and Their Use* — There are various types of magnetic particles available for use in magnetic particle examination. They are available as dry powders (fluorescent and nonfluorescent) ready for use as supplied (see 8.3), powder concentrates (fluorescent and nonfluorescent) for dispersion in water or suspending light petroleum distillates (see 8.4), magnetic slurries/paints (see 8.4.7), and magnetic polymer dispersions (see 8.4.8).

4.5 *Evaluation of Indications* — When the material to be examined has been properly magnetized, the magnetic particles have been properly applied, and the excess particles properly removed, there will be accumulations of magnetic particles at the points of flux leakage. These accumulations show the distortion of the magnetic field

and are called indications. Without disturbing the particles, the indications must be examined, classified, interpreted as to cause, compared with the acceptance standards, and a decision made concerning the disposition of the material that contains the indication.

4.6 *Typical Magnetic Particle Indications:*

4.6.1 *Surface Discontinuities* — Surface discontinuities, with few exceptions, produce sharp, distinct patterns (see Annex A).

4.6.2 *Near-Surface Discontinuities* — Near-surface discontinuities produce less distinct indications than those open to the surface. The patterns are broad, rather than sharp, and the particles are less tightly held (see Annex A).

5. Significance and Use

5.1 The magnetic particle method of nondestructive examination indicates the presence of surface and near-surface discontinuities in materials that can be magnetized (ferromagnetic). This method can be used for production examination of parts/components or structures and for field applications where portability of equipment and accessibility to the area to be examined are factors. The ability of the method to find small discontinuities can be enhanced by using fluorescent particles suspended in a suitable vehicle and by introducing a magnetic field of the proper strength whose orientation is as close as possible to 90° to the direction of the suspected discontinuity (see 4.3.2). Making the surface smoother improves mobility of the magnetic particles under the influence of the magnetic field to collect on the surface where magnetic flux leakage occurs.

6. Equipment

6.1 *Types* — There are a number of types of equipment available for magnetizing ferromagnetic parts and components. With the exception of a permanent magnet, all equipment requires a power source capable of delivering the required current levels to produce the magnetic field. The current used dictates the sizes of cables and the capability of relays, switching contacts, meters and rectifier if the power source is alternating current.

6.2 *Portability* — Portability, which includes the ability to hand carry the equipment, can be obtained from yokes. Their size limits their ability to provide the magnetic fields that can be obtained from equipment with larger current flows. General purpose mobile equipment which may be truck mounted is usually designed either for use with prods on the ends of two cables or with only the cables which are attached to the piece being examined, threaded through an opening in it or wrapped around it. Mobility is limited by the cable and size and the environment. Underwater examination on oil drilling platforms and oil production platforms offshore are examples of a hostile environment.

6.3 *Yokes* — Yokes are usually C-shaped electromagnets which induce a magnetic field between the poles (legs) and are used for local magnetization (Fig. 1). Many portable yokes have articulated legs (poles) that allow the legs to be adjusted to contact irregular surfaces or two surfaces that join at an angle.

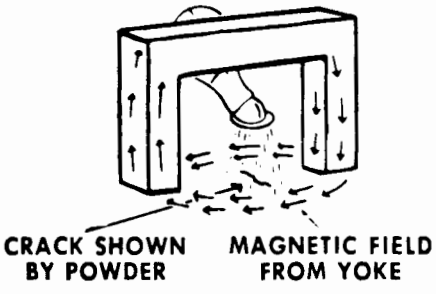
6.3.1 *Permanent Magnets* — Permanent magnets are available but their use may be restricted for many applications. Permanent magnets can lose their magnetic field generating capacity by being partially demagnetized by a stronger flux field, being damaged, or dropped. In addition, the particle mobility, created by AC and half-wave rectified current pulsations in electromagnetic yokes, is not present. Particles, steel filings, chips, and scale clinging to the poles can create a housekeeping problem.

6.4 *Prods* — Prods are used for local magnetizations, see Fig. 2. The prod tips that contact the piece should be aluminum, copper braid, or copper pads rather than solid copper. With solid copper tips, accidental arcing during prod placement or removal can cause copper penetration into the surface which may result in metallurgical damage (softening, hardening, cracking, etc.). See 12.3.1.1(a). Open-circuit voltages should not exceed 25 V.

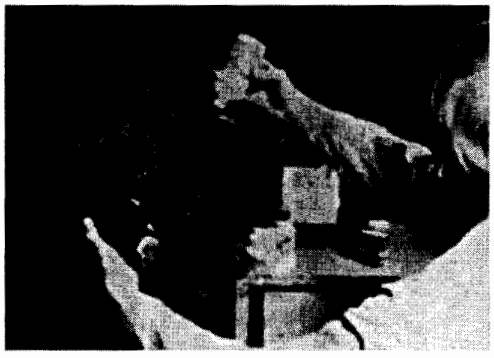
6.4.1 *Remote Control Switch* — A remote-control switch, which may be built into the prod handles, should be provided to permit the current to be turned on after the prods have been properly placed and to turn it off before the prods are removed in order to minimize arcing (arc burns). [See 12.3.1.1(a).]

6.5 *Black Light* — The black light must be capable of developing the required wavelengths of 330 to 390 nm with an intensity at the examination surface that satisfies 7.1.2. Wavelengths at or near 365 nm shall predominate. Suitable filters should remove the extraneous visible light emitted by black lights (violet or blue 405 and 435-nm Hg lines and greenish-yellow 577-nm Hg line). Some high-intensity black light bulbs may emit unacceptable amounts of greenish-yellow light which may cause fluorescent indications to become invisible. A drop, greater than 10%, in line voltage greater than ±10% can cause a change in black light output with consequent inconsistent performance. A constant voltage transformer should be used where there is evidence of voltage changes greater than 10%.

6.6 *Equipment Verification* — See Section 20.



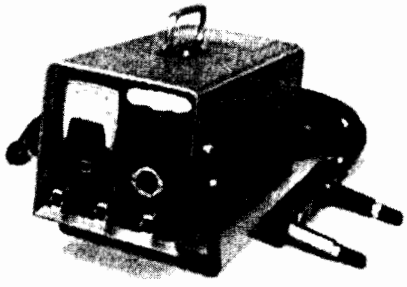
(a)



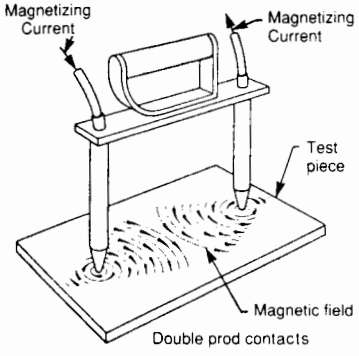
(b)

FIG. 1 YOKE METHOD OF PART MAGNETIZATION

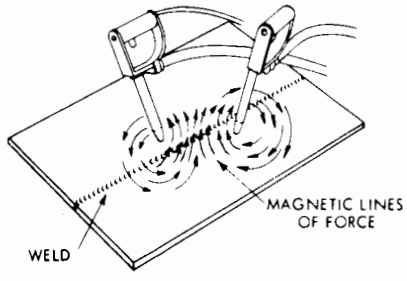
(a) Prod Magnetization



(b) Copper-Braided Tip Prods



(c) Single-Prod Contacts Magnetization



(d) Double-Prod Contacts

FIG. 2 LOCALIZED AREA MAGNETIZATION USING PROD TECHNIQUE

7. Examination Area

7.1 *Light Intensity for Examination* — Magnetic indications found using nonfluorescent particles are examined under visible light. Indications found using fluorescent particles must be examined under black (ultraviolet) light. This requires a darkened area with accompanying control of the visible light intensity.

7.1.1 *Visible Light Intensity* — The intensity of the visible light at the surface of the part/work piece undergoing examination should be a minimum of 100 foot candles (1000 lux). The intensity of ambient visible light in the darkened area where fluorescent magnetic particles examination is performed should not exceed 2 foot candles (20 lux).

7.1.1.1 *Field Inspections* — For some field inspections using nonfluorescent particles, visible light intensities as low as 50 foot candles (500 lux) may be used when agreed on by the contracting agency.

7.1.2 *Black (Ultraviolet) Light:*

7.1.2.1 *Black Light Intensity* — The black light intensity at the examination surface shall be not less than 1000 $\mu W/cm^2$ when measured with a suitable black light meter.

7.1.2.2 *Black Light Warm-up* — Allow the black light to warm up for a minimum of 5 min prior to its use or measurement of the intensity of the ultraviolet light emitted.

7.1.3 *Dark Area Eye Adaptation* — It is recommended that the inspector be in the darkened area for at least 3 min prior to examining parts using black light so that his eyes will adapt to dark viewing. **Caution** — Photochromic or permanently tinted lenses shall not be worn during examination.

7.2 *Housekeeping* — The examination area should be kept free of interfering debris. If fluorescent materials are involved, the area should also be kept free of fluorescent objects not related to the part/piece being examined.

8. Magnetic Particle Materials

8.1 *Particle Types* — The particles used in either dry or wet magnetic particle examination techniques are basically finely divided ferromagnetic materials which have been treated to impart color (fluorescent and nonfluorescent) in order to make them highly visible (contrasting) against the background of the surface being examined. The particles are designed for use either as a free flowing dry powder or for suspension at a given concentration in a suitable liquid medium.

8.2 *Particle Characteristics* — The magnetic particles must have high permeability to allow ease of magnetizing and attraction to the discontinuity and low retentivity so they will not be attracted (magnetic agglomeration) to each other. Control of particle size and shape is required to obtain consistent results. The particles should be nontoxic, free from rust, grease, paint, dirt, and other deleterious materials that might interfere with their use; see 20.5 and 20.6. Both dry and wet particles are considered safe when used in accordance with the manufacturer's instructions. They generally afford a very low hazard potential with regard to flammability and toxicity.

8.3 *Dry Particles* — Dry magnetic powders are designed to be used as supplied and are applied by spraying or dusting directly onto the surface of the part being examined. They are generally used on an expendable basis although the particles may be collected and reused. However, to maintain particle size and control possible contamination, this is not a normal practice. Dry powders may also be used under extreme environmental conditions. They are not affected by cold; therefore examination can be carried out at temperatures that would thicken or freeze wet baths. They are also heat resistant; some powders may be usable at temperatures up to 600°F (315°C). Some colored, organic coatings applied to dry particles to improve contrast lose their color at temperatures this high, making the contrast less effective. Fluorescent dry particles cannot be used at this high a temperature; the manufacturer should be contacted for the temperature limitation or tests should be run.

8.3.1 *Advantages* — The dry magnetic particle technique is generally superior to the wet technique for detection of near-surface discontinuities: (a) for large objects when using portable equipment for local magnetization; (b) superior particle mobility is obtained for relatively deep-seated flaws half-wave rectified current as the magnetizing source; (c) ease of removal.

8.3.2 *Disadvantages* — The dry magnetic particle technique; (a) cannot be used in confined areas without proper safety breathing apparatus; (b) Probability of Detection (POD) is appreciably less than the wet technique for fine surface discontinuities; (c) difficult to use in overhead magnetizing positions; (d) no evidence exists of complete coverage of part surface as with the wet technique; (e) lower production rates can be expected with the dry technique versus the wet technique; and (f) it is difficult to adapt to any type of automotive system.

8.3.3 *Nonfluorescent Colors* — Although dry magnetic particle powder can be almost any color, the most frequently employed colors are light gray, black, red, or yellow. The choice is generally based on maximum contrast with the surface to be examined. The examination is done under visible light.

8.3.4 *Fluorescent* — Fluorescent dry magnetic particles are also available, but are not in general use primarily because of their higher cost and use limitations. They require a black light source and a darkened work area. These requirements are not often available in the field-type location where dry magnetic particle examinations are especially suitable.

8.4 *Wet Particle Systems* — Wet magnetic particles are designed to be suspended in a vehicle such as water or light petroleum distillate at a given concentration for application to the test surface by flowing, spraying, or pouring. They are available in both fluorescent and nonfluorescent concentrates. In some cases the particles are premixed with the suspending vehicle by the supplier,

but usually the particles are supplied as a dry concentrate or paste concentrate which is mixed with the distillate or water by the user. The suspensions are normally used in wet horizontal magnetic particle equipment in which the suspension is retained in a reservoir and recirculated for continuous use. The suspension may also be used on an expendable basis dispensed from an aerosol.

8.4.1 *Primary Use* — Because the particles used are smaller, wet method techniques are generally used to locate smaller discontinuities than the dry method is used for. The liquid vehicles used will not perform satisfactorily when their viscosity exceeds 5cSt (5 mm^2/s) at the operating temperature. If the suspension vehicle is a hydrocarbon, its flash point limits the top temperature. Mixing equipment is usually required to keep wet method particles uniformly in suspension.

8.4.2 *Where Used* — The wet fluorescent method usually is performed indoors or in areas where shelter and ambient light level can be controlled and where proper application equipment is available.

8.4.3 *Color* — Fluorescent wet method particles glow a bright greenish-yellow when viewed under black light. Nonfluorescent particles are usually black or reddish brown, although other colors are available. The color often chosen for any given examination should be one that contrasts most with the test surface. Because contrast is invariably higher with fluorescent materials, these are utilized in most wet process examinations.

8.4.4 *Suspension Vehicles* — Generally the particles are suspended in a light petroleum (low-viscosity) distillate or conditioned water. (If sulfur or chlorine limits are specified, use Test Methods D 129 and D 808 to determine their values.

8.4.4.1 *Petroleum Distillates* — Low-viscosity light petroleum distillates vehicles (AMS 2641 Type 1 or equal) are ideal for suspending both fluorescent and nonfluorescent magnetic particles and are commonly employed.

(1) Advantages — Two significant advantages for the use of petroleum distillate vehicles are: (a) the magnetic particles are suspended and dispersed in petroleum distillate vehicles without the use of conditioning agents; and (b) the petroleum distillate vehicles provide a measure of corrosion protection to parts and the equipment used.

(2) Disadvantages — Principal disadvantages are flammability and availability. It is essential, therefore, to select and maintain readily available sources of supply of petroleum distillate vehicles that have as high a flash point as practicable to avoid possible flammability problems.

(3) Characteristics — Petroleum distillate vehicles to be used in wet magnetic particle examination should possess the following: (*a*) viscosity should not exceed 3.0 cSt (3 mm^2/s) at 100°F (38°C) and not more than 5.0 cSt (5 mm^2/s) at the lowest temperature at which the vehicle will be used; when tested in accordance with Test Method D 445, in order not to impede particle mobility (see 20.7.1), (*b*) minimum flash point, when tested in accordance with Test Methods D 93, should be 200°F (93°C) in order to minimize fire hazards (see 20.7.2), (*c*) odorless; not objectionable to user, (*d*) low inherent fluorescence if used with fluorescent particles; that is, it should not interfere significantly with the fluorescent particle indications (see 20.6.4.1), and (*e*) nonreactive; should not degrade suspended particles.

8.4.4.2 *Water Vehicles with Conditioning Agents* — Water may be used as a suspension vehicle for wet magnetic particles provided suitable conditioning agents are added which provide proper wet dispersing, in addition to corrosion protection for the parts being tested and the equipment in use. Plain water does not disperse some types of magnetic particles, does not wet all surfaces, and is corrosive to parts and equipment. On the other hand, water suspensions of magnetic particles are safer to use since they are nonflammable. The selection and concentration of the conditioning agent should be as recommended by the particle manufacturer. The following are recommended properties for water vehicles containing conditioning agents for use with wet magnetic particle examination:

(1) Wetting Characteristics — The vehicle should have good wetting characteristics; that is, wet the surface to be tested, give even, complete coverage without evidence of dewetting the test surface. Smooth test surfaces require that a greater percentage of wetting agent be added than is required for rough surface. Nonionic wetting agents are recommended (see 20.7.3).

(2) Suspension Characteristics — Impart good dispersability; that is, thoroughly disperse the magnetic particles, without evidence of particle agglomeration.

(3) Foaming — Minimize foaming; that is, it should not produce excessive foam which would interfere with indication formation or cause particles to form scum with the foam.

(4) Corrosiveness — It should not corrode parts to be tested or the equipment in which it is used.

(5) Viscosity Limit — The viscosity of the conditioned water should not exceed a maximum viscosity of 3 cSt (3 mm^2/s) at 100°F (38°C) (see 20.7.1).

(6) Fluorescence — The conditioned water should not fluoresce if intended for use with fluorescent particles.

(7) Nonreactiveness — The conditioned water should not cause deterioration of the suspended magnetic particles.

(8) Water pH — The pH of the conditioned water should not be less than 6.0 or exceed 10.5.

(9) Odor — The conditioned water should be essentially odorless.

8.4.5 *Concentration of Wet Magnetic Particle Suspension* — The initial bath concentration of suspended magnetic particles should be as specified or as recommended by the manufacturer and should be checked by settling volume measurements and maintained at the specified concentration on a daily basis. If the concentration is not maintained properly, test results can vary greatly (see 20.6).

8.4.6 *Application of Wet Magnetic Particles* (see 15.2).

8.4.7 *Magnetic Slurry/Paint Systems* — Another type of examination vehicle is the magnetic slurry/ paint type consisting of a heavy oil in which flakelike particles are suspended. The material is normally applied by brush before the part is magnetized. Because of the high viscosity, the material does not rapidly run off surfaces, facilitating the inspection of vertical or overhead surfaces. The vehicles may be combustible, but the fire hazard is very low. Other hazards are very similar to those of the oil and water vehicles previously described.

8.4.8 *Polymer-Based Systems* — The vehicle used in the magnetic polymer is basically a liquid polymer which disperses the magnetic particles and which cures to an elastic solid in a given period of time, forming fixed indications. Viscosity limits of standard wet technique vehicles do not apply. Care should be exercised in handling these polymer materials. Use in accordance with manufacturer's instructions and precautions. This technique is particularly applicable to examine areas of limited visual accessibility, such as bolt holes.

9. Part Preparation

9.1 *General* — The surface of the part to be examined should be essentially clean, dry, and free of contaminants such as dirt, oil, grease, loose rust, loose mill sand, loose mill scale, lint, thick paint, welding flux/slag, and weld splatter that might restrict particle movement. See 15.1.2 about applying dry particles to a damp/wet surface. When testing a local area, such as a weld, the areas adjacent to the surface to be examined, as agreed by the contracting parties, must also be cleaned to the extent necessary to permit detection of indications.

9.1.1 *Nonconductive Coatings* — Thin nonconductive coatings, such as paint in the order of 0.02 to 0.05 mm (1 or 2 mil) will not normally interfere with the formation of indications, but they must be removed at all points where electrical contact is to be made for direct magnetization. Indirect magnetization does not require electrical contact with the part/piece. See Section 12.2. If a nonconducting coating/plating is left on the area to be examined that has a thickness greater than 0.05 mm (2 mil), it must be demonstrated that discontinuities can be detected through the maximum thickness applied.

9.1.2 *Conductive Coatings* — A conductive coating (such as chrome plating and heavy mill scale on wrought products resulting from hot forming operations) can mask discontinuities. As with nonconductive coatings, it must be demonstrated that the discontinuities can be detected through the coating.

9.1.3 *Residual Magnetic Fields* — If the part/ piece holds a residual magnetic field from a previous magnetization that will interfere with the examination, the part must be demagnetized. See Section 18.

9.2 *Cleaning Examination Surface* — Cleaning of the test surface may be accomplished by detergents, organic solvents, or mechanical means. As-welded, as-rolled, as-cast, or as-forged surfaces are generally satisfactory, but if the surface is unusually nonuniform, as with burned-in sand or a very rough weld deposit, interpretation may be difficult because of mechanical entrapment of the magnetic particles. In case of doubt, any questionable area should be recleaned and reexamined (see 9.1). An extensive presentation of applicable cleaning methods is described in Annex A1 of Test Method E 165.

9.2.1 *Plugging and Masking Small Holes and Openings* — Unless prohibited by the purchaser, small openings and oil holes leading to obscure passages or cavities can be plugged or masked with a suitable nonabrasive material which is readily removed. In the case of engine parts, the material must be soluble in oil. Effective masking must be used to protect components that may be damaged by contact with the particles or particle suspension.

10. Sequence of Operations

10.1 *Sequencing Particle Application and Establishing Magnetic Flux Field* — The sequence of operation in magnetic particle examination applies to the relationship between the timing and application of particles and establishing the magnetizing flux field. Two basic techniques apply, that is, continuous (see 10.1.1 and 10.1.2) and residual (see 10.1.3), both of which are commonly employed in industry.

10.1.1 *Continuous Magnetization* — Continuous magnetization is employed for most applications utilizing

either dry or wet particles and should be used unless specifically prohibited in the contract, purchase order, or specification. The sequence of operation for the dry and the wet continuous magnetization techniques are significantly different and are discussed separately in 10.1.1.1 and 10.1.1.2.

10.1.1.1 *Dry Continuous Magnetization Technique* — Unlike a wet suspension, dry particles lose most of their mobility when they contact the surface of a part. Therefore, it is imperative that the part/area of interest be under the influence of the applied magnetic field while the particles are still airborne and free to be attracted to leakage fields. This dictates that the flow of magnetizing current be initiated prior to the application of dry magnetic particles and terminated after the application of powder has been completed and any excess has been blown off. Magnetizing currents of the half-wave rectified alternating and unrectified AC provide additional particle mobility on the surface of the part. Examination with dry particles is usually carried out in conjunction with prod-type localized magnetizations, and buildup of indications is observed as the particles are being applied.

10.1.1.2 *Wet Continuous Magnetization Technique* — The wet continuous magnetization technique generally applies to those parts processed on a horizontal wet type unit. In practice, it involves bathing the part with the examination medium to provide an abundant source of suspended particles on the surface of the part and terminating the bath application immediately prior to cutting off of the magnetizing current. The duration of the magnetizing current is typically on the order of $\frac{1}{2}$ s with two or more shots given to the part.

10.1.1.3 *Polymer or Slurry Continuous Magnetization Technique* — Prolonged or repeated periods of magnetization are often necessary for polymer- or slurry-base suspensions because of slower inherent magnetic particle mobility in the high-viscosity suspension vehicles.

10.1.2 *True Continuous Magnetization Technique* — In this technique, the magnetizing current is sustained throughout both the processing and examination of the part.

10.1.3 *Residual Magnetization Techniques:*

10.1.3.1 *Residual Magnetization* — In this technique, the examination medium is applied after the magnetizing force has been discontinued. It can be used only if the material being tested has relatively high retentivity so the residual leakage field will be of sufficient strength to attract and hold the particles and produce indications. This technique may be advantageous for integration with production or handling requirements or for intentionally

FIG. 3 COIL MAGNETIZATION

limiting the sensitivity of the examination. It has found wide use examining pipe and tubular goods. Unless demonstrations with typical parts indicate that the residual field has sufficient strength to produce relevant indications of discontinuities (see 20.8) when the field is in proper orientation, the continuous method should be used.

10.1.3.2 *Current Quick Break* — Equipment, full-wave rectified AC, for residual magnetization must be designed to provide a consistent quick break of the magnetizing current.

11. Types of Magnetizing Currents

11.1 *Basic Current Types* — The four basic types of current used in magnetic particle examination to establish part magnetization are alternating current, single phase half-wave rectified alternating current, full-wave rectified alternating current, and for a special application, DC.

11.1.1 *Alternating Current (AC)* — Part magnetization with alternating current is preferred for those applications where examination requirements call for the detection of discontinuities, such as fatigue cracks, that are open to the surface. Associated with AC is a "skin effect" that confines the magnetic field at or near to the surface of a part. In contrast, both half-wave rectified alternating current and full-wave rectified alternating current produce a magnetic field having maximum penetrating capabilities which should be used when near-surface discontinuities are of concern. Alternating current is also extensively used for the demagnetization of parts after examination. The through-coil technique is normally used for this purpose due to its simple, fast nature. See Fig. 3.

11.1.2 *Half-Wave Rectified Alternating Current* — Half-wave rectified alternating current is frequently used in conjunction with dry particles and localized magnetization (for example, prods or yokes) to achieve some depth of penetration for detection of typical discontinuities found in weldments and ferrous castings. As with AC for magnetization, single-phase current is utilized and average value measured as "magnetizing current."

11.1.3 *Full-Wave Rectified Alternating Current* — Full-wave rectified alternating current may utilize single- or three-phase current. Three-phase current has the advantage of lower line amperage whereas single-phase equipment is less expensive. Full-wave rectified AC is commonly used when the residual method is to be employed. With the continuous method, full-wave rectified AC is used for magnetization of coated and plated parts. Because particle movement, either dry or wet is noticeably slower, precautions must be taken to ensure that sufficient time is allowed for formation of indications.

11.1.4 *Direct Current (DC)* — A bank of batteries or a DC generator produce a direct magnetizing current. They have largely given way to half-wave rectified or full-wave rectified AC except for a few specialized applications, primarily because of battery cost and maintenance. One such example is the charging of a bank of capacitors, which on discharge is used to establish a residual magnetic field in tubing, casing, line pipe, and drill pipe.

12. Part Magnetization Techniques

12.1 *Examination Coverage* — All examinations should be conducted with sufficient area overlap to assure the required coverage at the specified sensitivity has been obtained.

12.2 *Direct and Indirect Magnetization* — A part can be magnetized either directly or indirectly. For direct magnetization the magnetizing current is passed directly through the part creating a circular magnetic field in the part. With indirect magnetization techniques a magnetic field is induced in the part which can create a circular/toroidal, longitudinal, or multidirectional magnetic field in the part. The techniques described in 20.8 for verifying that the magnetic fields have the anticipated direction and strength should be employed. This is especially important when using the multidirection technique to examine complex shapes.

12.3 *Choosing a Magnetization Technique* — The choice of direct or indirect magnetization will depend on such factors as size, configuration, or ease of processing. Table 1 compares the advantages and limitations of the various methods of part magnetization.

12.3.1 *Direct Contact Magnetization* — For direct magnetization, physical contact must be made between the ferromagnetic part and the current carrying electrodes connected to the power source. Both localized area magnetization and overall part magnetization are direct contact means of part magnetization achieved through the use of prods, head and tailstock, clamps, and magnetic leeches.

12.3.2 *Localized Area Magnetization:*

12.3.2.1 *Prod Technique* — The prod electrodes are first pressed firmly against the test part [Fig. 2(a)]. The magnetizing current is then passed through the prods and into the area of the part in contact with the prods. This establishes a circular magnetic field in the part around and between each prod electrode, sufficient to carry out a local magnetic particle examination (Figs. 2(c) and 2(d)). **Caution:** Extreme care should be taken to maintain clean prod tips, to minimize heating at the point of contact and to prevent arc burns and local overheating on the surface being examined since these may cause adverse effects on material properties. Arc burns cause metallurgical damage; if the tips are solid copper, copper penetration into the part may occur. Prods should not be used on machined surfaces or on aerospace component parts.

(1) Unrectified AC limits the prod technique to the detection of surface discontinuities. Half-wave rectified AC is most desirable since it will detect both surface and near-surface discontinuities. The prod technique generally utilizes dry magnetic particle materials due to better particle mobility. Wet magnetic particles are not generally used with the prod technique because of potential electrical and flammability hazards.

(2) Proper prod examination requires a second placement with the prods rotated approximately 90° from the first placement to assure that all existing discontinuities are revealed. Depending on the surface coverage requirements, overlap between successive prod placements may be necessary. On large surfaces, it is good practice to layout a grid for prod/yoke placement.

12.3.2.2 *Manual Clamp/Magnetic Leech Technique* — Local areas of complex components may be magnetized by electrical contacts manually clamped or attached with magnetic leeches to the part (Fig. 4). As with prods, sufficient overlap may be necessary if testing of the contact location is required.

12.3.2.3 *Overall Magnetization:*

(1) Head and Tailstock Contact — Parts may be clamped between two electrodes (such as a head and tailstock of horizontal wet magnetic particle equipment) and the magnetizing current applied directly through the part (Fig. 5). The size and shape of the part will determine

TABLE 1
ADVANTAGES AND LIMITATIONS OF THE VARIOUS WAYS OF MAGNETIZING A PART

Magnetizing Technique and Material Form	Advantages	Limitations
I. Direct Contact Part Magnetization (see 12.3.1)		
Head/Tailstock Contact Solid, relatively small parts (castings, forgings, machined pieces) that can be processed on a horizontal wet unit	1. Fast, easy technique 2. Circular magnetic field surrounds current path. 3. Good sensitivity to surface and near-surface discontinuities. 4. Simple as well as relatively complex parts can usually be easily processed with one or more shots. 5. Complete magnetic path is conducive to maximizing residual characteristics of material.	1. Possibility of arc burns if poor contact conditions exist. 2. Long parts should be magnetized in sections to facilitate bath application without resorting to an overly long current shot.
Large castings and forgings	1. Large surface areas can be processed and examined in relatively short time.	1. High amperage requirements (16 000 to 20 000 A) dictate special DC power supply.
Cylindrical parts such as tubing, pipe, hollow shafts, etc.	1. Entire length can be circularly magnetized by contacting, end to end.	1. Effective field limited to outside surface and cannot be used for inside diameter examination. 2. Ends must be conductive to electrical contacts and capable of carrying required current without excessive heat. Cannot be used on oil country tubular goods because of possibility of arc burns.
Long solid parts such as billets, bars, shafts, etc.	1. Entire length can be circularly magnetized by contacting, end to end. 2. Current requirements are independent of length. 3. No end loss.	1. Voltage requirements increase as length increases due to greater impedance of cable and part. 2. Ends must be conductive to electrical contact and capable of carrying required current without excessive heat.
Prods: Welds	1. Circular field can be selectively directed to weld area by prod placement. 2. In conjunction with half-wave rectified alternating current and dry powder, provides excellent sensitivity to subsurface discontinuities as well as surface type. 3. Flexible, in that prods, cables, and power packs can be brought to examination site.	1. Only small area can be examined at one time. 2. Arc burns due to poor contact. 3. Surface must be dry when dry powder is being used. 4. Prod spacing must be in accordance with the magnetizing current level.

TABLE 1 (CONT'D)
ADVANTAGES AND LIMITATIONS OF THE VARIOUS WAYS OF MAGNETIZING A PART

Magnetizing Technique and Material Form	Advantages	Limitations
Large castings or forgings	1. Entire surface area can be examined in small increments using nominal current values. 2. Circular field can be concentrated in specific areas that historically are prone to discontinuities. 3. Equipment can be brought to the location of parts that are difficult to move. 4. In conjunction with half-wave rectified alternating current and dry powder, provides excellent sensitivity to near surface subsurface type discontinuities that are difficult to locate by other methods.	1. Coverage of large surface area requires a multiplicity of shots that can be very time-consuming. 2. Possibility of arc burns due to poor contact. Surface should be dry when dry powder is being used.
II. Indirect Part Magnetization (see 12.3.2)		
Central Conductor Miscellaneous parts having holes through which a conductor can be placed such as: Bearing race Hollow cylinder Gear Large nut Large clevis Pipe coupling, casing/tubing	1. No electrical contact to part and possibility of arc burns eliminated. 2. Circumferentially directed magnetic field is generated in all surfaces surrounding the conductor (inside diameter, faces, etc.). 3. Ideal for those cases where the residual method is applicable. 4. Light weight parts can be supported by the central conductor. 5. Multiple turns may be used to reduce current required.	1. Size of conductor must be ample to carry required current. 2. Ideally, conductor should be centrally located within hole. 3. Larger diameters require repeated magnetization with conductor against inside diameter and rotation of part between processes. Where continuous magnetization technique is being employed, examination is required after each magnetization.
Tubular type parts such as: Pipe/Casting Tubing Hollow shaft	1. No electrical contact of part required. 2. Inside diameter as well as outside diameter examination. 3. Entire length of part circularly magnetized.	1. Outside surface sensitivity may be somewhat less than that obtained on the inside surface for large diameter and extremely heavy wall.
Large valve bodies and similar parts	1. Provides good sensitivity for detection of discontinuities located on internal surfaces.	1. Outside surface sensitivity may be somewhat less than that obtained on the inside diameter for heavy wall.
Coil/Cable Wrap Miscellaneous medium-sized parts where the length predominates such as a crankshaft	1. All generally longitudinal surfaces are longitudinally magnetized to effectively locate transverse discontinuities.	1. Length may dictate multiple shot as coil is repositioned.
Large castings, forgings, or shafting	1. Longitudinal field easily attained by means of cable wrapping.	1. Multiple magnetization may be required due to configuration of part.

TABLE 1 (CONT'D)
ADVANTAGES AND LIMITATIONS OF THE VARIOUS WAYS OF MAGNETIZING A PART

Magnetizing Technique and Material Form	Advantages	Limitations
Miscellaneous small parts	1. Easy and fast, especially where residual magnetization is applicable. 2. No electrical contact. 3. Relatively complex parts can usually be processed with same ease as those with simple cross section.	1. L/D (length/diameter) ratio important consideration in determining adequacy of ampere-turns. 2. Effective L/D ratio can be altered by utilizing pieces of similar cross-sectional area. 3. Use smaller coil for more intense field. 4. Sensitivity diminishes at ends of part due to general leakage field pattern. 5. Quick break desirable to minimize end effect on short parts with low L/D ratio.
Induced Current Fixtures Examination of ring-shaped part for circumferential-type discontinuities.	1. No electrical contact. 2. All surfaces of part subjected to toroidal-type magnetic field. 3. Single process for 100% coverage. 4. Can be automated.	1. Laminated core required through ring. 2. Type of magnetizing current must be compatible with method. 3. Other conductors encircling field must be avoided. 4. Large diameters require special consideration.
Ball examination	1. No electrical contact. 2. 100% coverage for discontinuities in any direction with three-step process and proper orientation between steps. 3. Can be automated.	1. For small-diameter balls, limited to residual magnetization.
Disks and gears	1. No electrical contact. 2. Good sensitivity at or near periphery or rim. 3. Sensitivity in various areas can be varied by core or pole-piece selection.	1. 100% coverage may require two-step process with core or pole-piece variation, or both. 2. Type of magnetizing current must be compatible with part geometry.
Yokes: Examination of large surface areas for surface-type discontinuities.	1. No electrical contact. 2. Highly portable. 3. Can locate discontinuities in any direction with proper orientation.	1. Time consuming. 2. Must be systematically repositioned in view of random discontinuity orientation.
Miscellaneous parts requiring examination of localized areas.	1. No electrical contact. 2. Good sensitivity to direct surface discontinuities. 3. Highly portable. 4. Wet or dry technique. 5. Alternating-current type can also serve as demagnetizer in some instances.	1. Must be properly positioned relative to orientation or discontinuities. 2. Relatively good contact must be established between part and poles. 3. Complex part geometry may cause difficulty. 4. Poor sensitivity to subsurface-type discontinuities except in isolated areas.

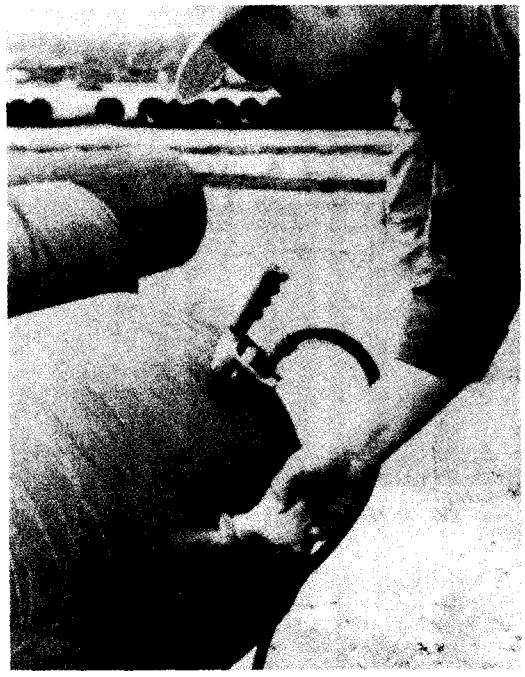


FIG. 4 DIRECT-CONTACT MAGNETIZATION THROUGH MAGNETIC LEECH CLAMP OF PART

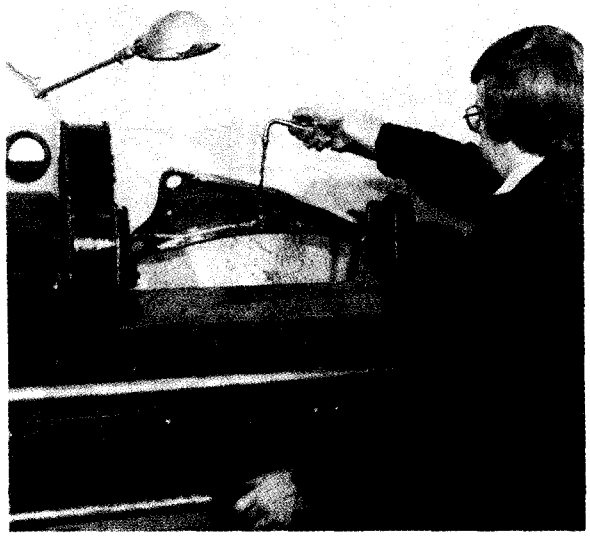


FIG. 5 DIRECT CONTACT MAGNETIZATION THROUGH HEAD/TAILSTOCK

whether both field directions can be obtained with such equipment.

(2) Clamps — The magnetizing current may be applied to the test part by clamping the current carrying electrodes to the part, producing a circular magnetic field (Fig. 6).

(3) Multidirectional Magnetization Technique — With suitable circuitry, it is possible to produce a multidirectional (oscillating) field in a part by selectively switching the magnetic field within the part between electrode contacts/clamps positioned approximately 90 deg. apart. This permits building up indications in all possible directions and may be considered the equivalent of magnetizing in two or more directions (Fig. 7). On some complex shapes as many as 16 to 20 steps may be required with conventional equipment. With multidirectional magnetization, it is usually possible to reduce the magnetizing steps required by more than half. It is essential that the wet continuous method be used and that the magnetic field direction and relative intensity be determined by one or more of the techniques described in 20.8.

12.3.3 *Indirect Magnetization* — Indirect part magnetization involves the use of a preformed coil, cable wrap, yoke, or a central conductor to induce a magnetic field. Coil, cable wrap, and yoke magnetization are referred to as longitudinal magnetization in the part (see 13.3).

12.3.3.1 *Coil and Coil Magnetization* — When coil (Fig. 3) or cable wrap (Fig. 8) techniques are used, the magnetic field strength is proportional to ampere turns and depends on simple geometry (see 14.3.2).

12.3.3.2 *Central Conductor, Induced Current Magnetization* — Indirect circular magnetization of hollow pieces/parts can be performed by passing the magnetizing current through a central conductor [Figs. 9(a) and 9(b)] or cable used as a central conductor or through an induced current fixture [Fig. 9(c)].

12.3.3.3 *Yoke Magnetization* — A magnetic field can be induced into a part by means of an electromagnet (see Fig. 1), where the part or a portion thereof becomes the magnetic path between the poles (acts as a keeper) and discontinuities preferentially transverse to the alignment of the pole pieces are indicated. Most yokes are energized by AC, half-wave rectified AC, or full-wave rectified AC. A permanent magnet can also introduce a magnetic field in the part but its use is restricted (see 6.3.1).

13. Direction of Magnetic Fields

13.1 *Discontinuity Orientation vs. Magnetic Field Direction* — Since indications are not normally obtained when discontinuities are parallel to the magnetic field, and since indications may occur in various or unknown directions in a part, each part must be magnetized in at least two directions approximately at right angles to each other as noted in 5.3.2. On some parts circular magnetization may be used in two or more directions, while on

FIG. 6 DIRECT CONTACT OVERALL MAGNETIZATION

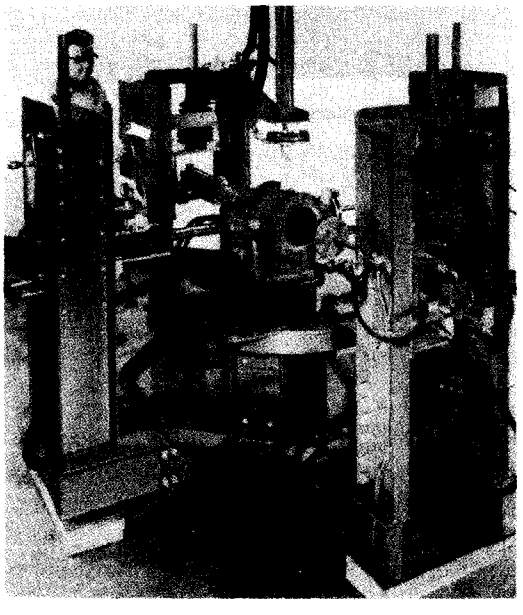


FIG. 7 MULTIDIRECTIONAL-OVERALL MAGNETIZATION

others both circular and longitudinal magnetization are used. A multidirectional field can also be employed to achieve part magnetization in more than one direction.

13.2 *Circular Magnetization* — Circular magnetization (Fig. 10) is the term used when electric current is passed through a part, or by use of a central conductor (see 12.3.3.2) through a central opening in the part, inducing a magnetic field at right angles to the current flow.

13.3 *Toroidal Magnetization* — When magnetizing a part with a toroidal shape, such as a solid wheel or the disk with a center opening, an induced field that is radial to the disk is most useful for the detection of discontinuities in a circumferential direction. In such applications this field may be more effective than multiple shots across the periphery.

13.4 *Longitudinal Magnetization* — Longitudinal magnetization (Fig. 11) is the term used when a magnetic field is generated by an electric current passing through a multiturn, Fig. 12, or laminated coil, Fig. 13, which encloses the part or section of the part to be examined.

13.5 *Multidirectional Magnetization* — The magnetic fields may be induced in the part by passing current through the part from different directions (see 12.3.2.3 and Fig. 14). Artificial flaws, circular shims, or known defects should be used to establish magnetic field direction.

14. Magnetic Field Strength

14.1 *Magnetizing Field Strengths* — To produce interpretable indications, the magnetic field in the part must have sufficient strength and proper orientation. For the indications to be consistent, this field strength must be controlled within reasonable limits, usually ±25%. Factors that affect the strength of the field are the size, shape, section thickness, material of the part/ piece, and the technique of magnetization. Since these factors vary widely, it is difficult to establish rigid rules for magnetic field strengths for every conceivable configuration.

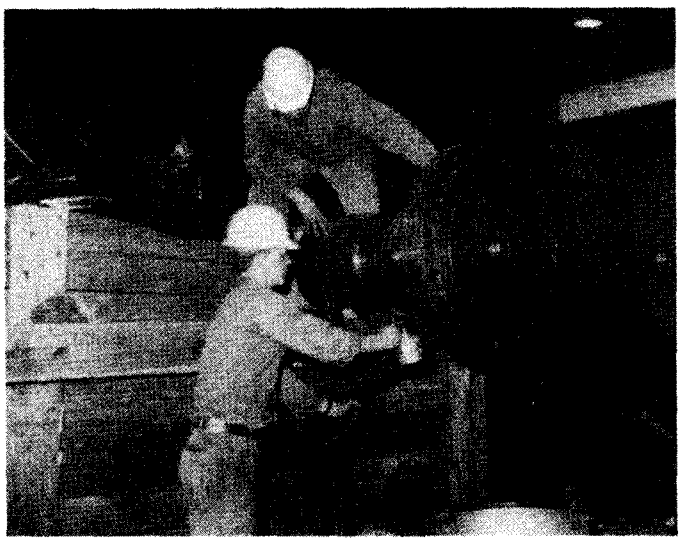


FIG. 8 CABLE MAGNETIZATION

14.2 *Establishing Field Strengths* — Sufficient magnetic field strength can be established by:

14.2.1 *Known Discontinuities* — Experiments with similar/identical parts having known discontinuities.

14.2.2 *Artificial Discontinuities* — The "pie" field indicator (Fig. 15) and slotted shims (Fig. 16) are artificial discontinuities. See 20.8.

14.2.3 *Hall-effect Probe-Tangential Field Strengths* — Tangentially applied field strengths, as measured with a Hall-effect probe/sensor, in the range from 30 to 60 G (2.4 to 4.8 kAM^{-1}) should be adequate. See 20.8. Under some circumstances some fields in the range from 10 to 150 G may be required.

14.2.4 *Using Empirical Formulas* — Section 14.3 has four empirical formulas for establishing magnetic field strengths; they are rules of thumb. As such, they must be used with judgment. Their use may lead to:

14.2.4.1 Over magnetization, which causes excessive particle background that makes interpretation more difficult if not impossible.

14.2.4.2 Poor coverage.

14.2.4.3 Poor choice of test geometries.

14.2.4.4 A combination of the above.

14.3 *Guidelines for Establishing Magnetic Fields* — The following guidelines can be effectively applied for establishing proper levels of circular and longitudinal magnetization.

14.3.1 *Circular Magnetization — Magnetic Field Strength:*

14.3.1.1 *Central Conductor Induced Magnetization* — Central conductors are widely used in magnetic particle examination to provide:

(1) A circular field on both the inside surface and outside surface of tubular pieces that cannot be duplicated by the direct current technique.

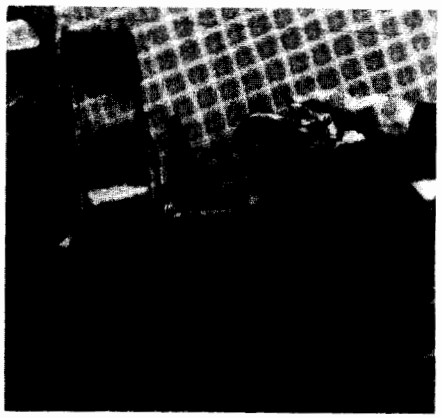
(2) A non-contact means of part magnetization virtually eliminating the possibility of arc burning the material, as can be the case with current flow through contacts, such as prods or clamps.

(3) Substantial processing advantages over direct contact techniques on ring-shaped parts.

(4) In general it is desirable to centrally locate a central conductor to permit the entire circumference of the part to be processed at one time. The resulting field is concentric relative to the axis of the piece and is maximum at the inside surface. The strength of the magnetic field should be verified by the means discussed in 20.8. With a centrally located central conductor, the magnetizing current requirements would be the same as a solid piece having the same outside diameter.

(5) When using offset central conductors the conductor passing through the inside of the part is placed against an inside wall of the part. The current shall be from 12 A per mm of part diameter to 32 A per mm of part diameter (300 to 800 A/in.). The diameter of the part shall be taken as the largest distance between any two points on the outside circumference of the part. Generally

(*a*) Use of Central Conductor on Multipart Magnetization



(*b*) Use of Central Conductor for Localized Magnetization

(*c*) Use of a Special Induced Current Fixture

FIG. 9 CENTRAL CONDUCTOR INDUCED MAGNETIZATION

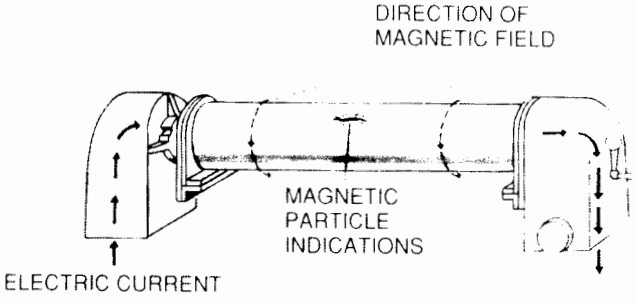


FIG. 10 CIRCULAR MAGNETIZATION

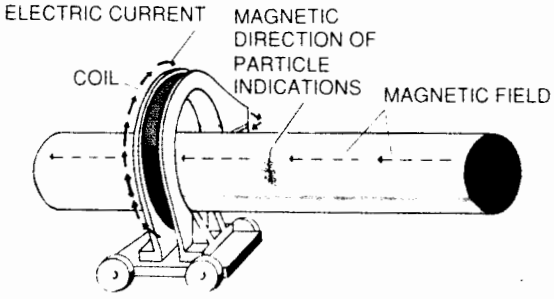


FIG. 11 LONGITUDINAL MAGNETIZATION

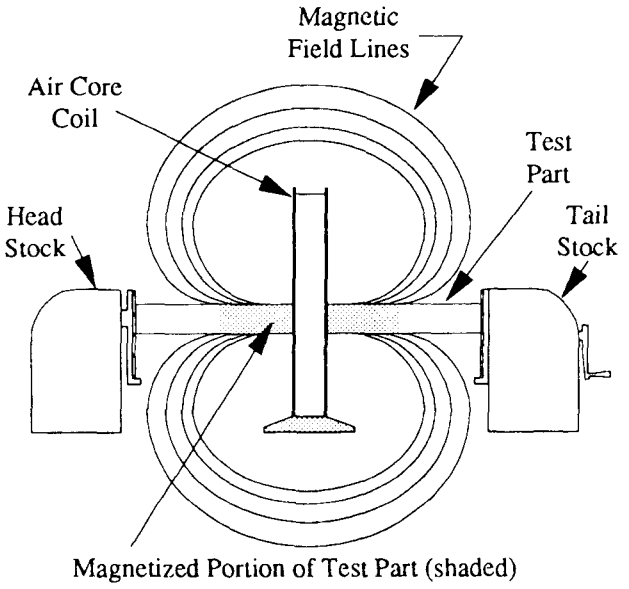


FIG. 12 MAGNETIC FIELD PRODUCED BY AN AIR CORE COIL

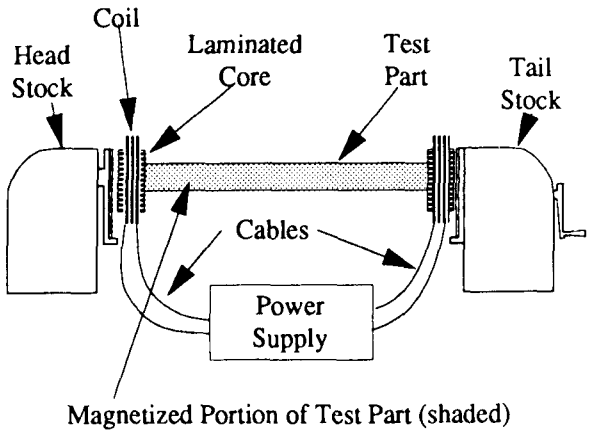


FIG. 13 MAGNETIC FIELD PRODUCED BY A LAMINATED CORE COIL

currents will be 500 A/in. (20 A per mm) or lower with the higher currents (up to 800 A/ in.) being used to examine for inclusions or to examine low permeability alloys such as precipitation-hardening steels. For examinations used to locate inclusions in precipitation-hardening steels even higher currents, up to 1000 A/in. (40 A per mm) may be used. The distance along the part circumference which may be effectively examined shall be taken as approximately four times the diameter of the central conductor, as illustrated Fig. 17. The entire circumference shall be examined by rotating the part on the conductor, allowing for approximately a 10% magnetic field overlap. Less overlap, different current levels, and larger effective regions (up to 360°) may be used if the presence of suitable field levels is verified.

14.3.1.2 Localized Magnetization:

(1) Using Prods — With prods, the strength circular magnetization is proportional to the amperage used but varies with the prod spacing and thickness of the section being examined. It is recommended that a magnetizing current from 1 in. (90 to 110 A/25 mm) of prod spacing should be used for material $^{3}/_{4}$ in. (19 mm) and over in thickness. Prolonged energizing cycles may cause undesirable localized overheating. Prod spacing should not exceed 8 in. (200 mm). Prod spacing less than 3 in. (75 mm) is usually not practical due to banding of the particles around the prods. When the area of examination exceeds a width of one quarter of the prod spacing, measured from a centerline connecting the prod centers, the magnetic field intensity should be verified at the edges of the area being examined.

(2) Using Yokes — The field strength of a yoke (or a permanent magnet) can be empirically determined by measuring its lifting power (see 20.3.6). If a Hall-effect probe is used, it shall be placed on the surface midway between the poles.

14.3.2 *Air-Core Coil Longitudinal Magnetization* — Longitudinal part magnetization is produced by passing a current through a multiturn coil encircling the part or section of the part to be examined. A magnetic field is produced parallel to the axis of the coil. The unit of measurement is ampere turns (NI) (the actual amperage multiplied by the number of turns in the encircling coil or cable). The effective field extends on either side of the coil a distance approximately equal to the radius of the coil being employed. Long parts should be examined in sections not to exceed this length. There are four empirical longitudinal magnetization formulas employed for using encircling coils, the formula to be used depending on the fill factor. The formulas are included for historical continuity only. If used its use should be limited to simple shaped parts. It would be quicker and more accurate to use a Gauss (Tesla) meter, lay its probe on the part and measure the field rather than to calculate using the formulas.

14.3.2.1 *Low Fill-Factor Coils* — In this case, the cross-sectional area of the fixed encircling coil greatly exceeds the cross-sectional area of the part (less than 10% coil inside diameter). For proper part magnetization, such parts should be placed well within the coils and close to the inside wall of the coil. With this low fill-factor, adequate field strength for eccentrically positioned parts with a length-over-diameter ratio (*L/D*) between 3

FIG. 14 MULTIDIRECTIONAL MAGNETIZATION

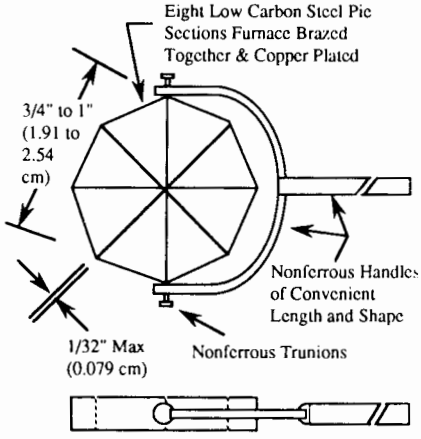
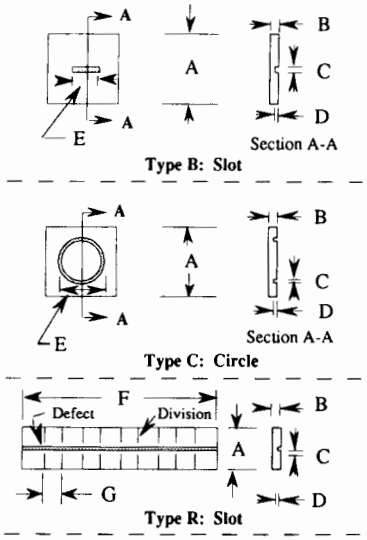


FIG. 15 MAGNETIC FIELD INDICATOR



Item	Dimension	Tolerance
A	(1)	± 1 mm
B	0.05 mm	± 0.0001 mm
C	0.005 mm	± 0.0001 mm
D	See 20.4.2	± 0.0001 mm
E	(1)	± 1mm
F	(1)	± 1 mm
G	(1)	± 1mm

(1) As specified by the manufacturer. These dimensions are not critical, see 20.4.8.

FIG. 16 TYPICAL SLOTTED SHIM DESIGNS

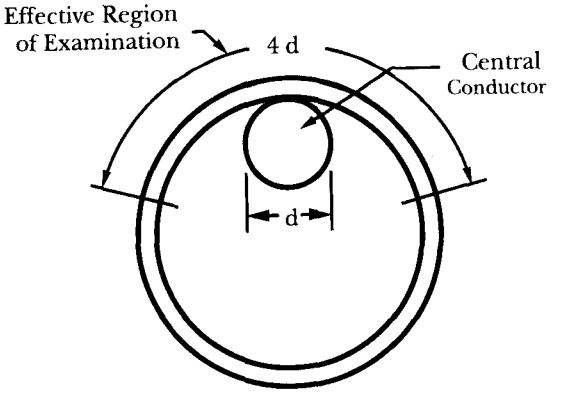


FIG. 17 APPROXIMATE EFFECTIVE REGION OF EXAMINATION WHEN USING AN OFFSET CENTRAL CONDUCTOR (THREADER BAR)

and 15 is calculated from the following equations:

(1) Parts With Low Fill-Factor Positioned Close to Inside Wall of Coil:

$$NI = K/(L/D)(\pm 10\%) \quad (1)$$

where:

N = number of turns in the coil,
I = coil current to be used, amperes (A),
K = 45 000 (empirically derived constant),
L = part, length, in., (see Note),
D = part diameter, in.; for hollow parts, see 14.3.2.4, and
NI = ampere turns.

For example, a part 15 in. (38.1 cm) long with 5-in. (12.7-cm) outside diameter has an L/D ratio of 15/5 or 3. Accordingly, the ampere turn requirement (NI = 45 000/3) to provide adequate field strength in the part would be 15 000 ampere turns. If a five-turn coil or cable is used, the coil amperage requirements would be (I = 15 000/5) = 3000 A (±10%). A 500 turn coil would require 30 A (±10%).

(2) Parts with a Low Fill-Factor Positioned in the Center of the Coil:

$$NI = KR/\{(6L/D) - 5\}(\pm 10\%) \quad (2)$$

where:

N = number of turns in the coil,
I = coil current to be used, A,
K = 43 000 (empirically derived constant),
R = coil radius, in.,
L = part length, in. (see Note),
D = part diameter, in., for hollow parts (see 14.3.2.4), and
NI = ampere turns.

For example, a part 15 in. (38.1 cm) long with 5-in. (12.7-cm) outside diameter has a L/D ratio of 15/5 or 3. If a five-turn 12-in. diameter (6-in. radius) (30.8-cm diameter [15.4-cm radius)] coil or cable is used, (*1*) the ampere turns requirement would be as follows:

$$NI = \frac{(43\,000 \times 6)}{[(6 \times 3) - 5]} \text{ or } 19\,846$$

and (2) the coil amperage requirement would be as follows:

$$\frac{19\,846}{5} \text{ or } 3\,969 \text{ A } (\pm 10\%)$$

14.3.2.2 *Intermediate Fill-Factor Coils* — When the cross section of the coil is greater than twice and less than ten times the cross section of the part being examined:

$$NI = (NI)_{hf}\,(10 - Y) + (NI)_{lf}\,(Y - 2)/8 \quad (3)$$

where:

NI_{hf} = value of NI calculated for high fill-factor coils using Eq 4,
NI_{lf} = value of NI calculated for low fill-factor coils using Eq 1 or Eq 2, and
Y = ratio of the cross-sectional area of the coil to the cross section of the part. For example, if the coil has an inside diameter of 10 in. (25.4 cm) and part (a bar) has an outside diameter of 5 in. (12.2 cm)

$$Y = [\pi(5)^2]/[\pi(2.5)^2] = 4$$

14.3.2.3 *High Fill-Factor Coils* — In this case, when fixed coils or cable wraps are used and the cross-sectional area of the coil is less than twice the cross-sectional area (including hollow portions) of the part, the coil has a high fill-factor.

(1) For Parts Within a High Fill-Factor Positioned Coil and for Parts with an L/D ratio equal to or greater than 3:

$$NI = \frac{K}{\{(L/D) + 2\}}(\pm 10\%) \quad (4)$$

where:

N = number of turns in the coil or cable wrap.
I = coil current, A,
K = 35 000 (empirically derived constant),
L = part length, in.,
D = part diameter, in., and
NI = ampere turns.

For example, the application of Eq 4 can be illustrated as follows: a part 10 in. (25.4 cm) long-with 2-in. (5.08-cm) outside diameter would have an L/D ratio of 5 and an ampere turn requirements of NI = 35 000/ (5 + 2) or 5000 (±10%) ampere turns. If a five-turn coil or cable wrap is employed, the amperage requirement is 5000/5 or 1000 A (±10%).

Note — For L/D ratios less than 3, a pole piece (ferromagnetic material approximately the same diameter as part) should be used to effectively increase the L/D ratio or utilize an alternative magnetization method such as induced current. For L/D ratios greater than 15, a maximum L/D value of 15 should be used for all formulas cited above.

14.3.2.4 *L/D Ratio for a Hollow Piece* — When calculating the L/D ratio for a hollow piece, D shall be replaced with an effective diameter D_{eff} calculated using:

$$D_{eff} = [(A_t - A_h)/\pi]^{1/2}$$

where:

A_t = total cross-sectional area of the part, and
A_h = cross-sectional area of the hollow portion(s) of the part.

For a cylindrical piece, this is equivalent to:

$$D_{eff} = [(OD)^2 - (ID)^2]^{1/2}$$

where:

OD = outside diameter of the cylinder, and
ID = inside diameter of the cylinder.

15. Application of Dry and Wet Magnetic Particles

15.1 *Dry Magnetic Particles:*

15.1.1 *Magnetic Fields for Dry Particles* — Dry magnetic powders are generally applied with the continuous magnetizing techniques utilizing AC or half-wave rectified AC or yoke magnetization. A current duration of at least ½ s should be used. The current duration should be short enough to prevent any damage from overheating or from other causes. It should be noted that AC and half-wave rectified AC impart better particle mobility to the powder than DC or full-wave rectified AC. Dry magnetic powders are widely used for magnetic particle examination of large parts as well as on localized areas such as welds. Dry magnetic particles are widely used for oil field applications and are frequently used in conjunction with capacitor discharge style equipment and the residual method.

15.1.2 *Dry Powder Application* — Dry powders should be applied in such a manner that a light uniform, dust-like coating settles upon the surface of the part/ piece while it is being magnetized. Dry particles must not be applied to a wet surface; they will have limited mobility. Neither should they be applied where there is excessive wind. The preferred application technique suspends the particles in air in such a manner that they reach the part surface being magnetized in a uniform cloud with a minimum of force. Usually, specially designed powder blowers and hand powder applicators are employed. (Figs. 1b and 4). Dry particles should not be applied by pouring, throwing, or spreading with the fingers.

15.1.3 *Excess Powder Removal* — Care is needed in both the application and removal of excess dry powder. While the magnetizing current is present, care must be exercised to prevent the removal of particles attracted by a leakage field that may prove to be a relevant indication of a discontinuity.

15.1.4 *Near-surface Discontinuities Powder Patterns* — In order to recognize the broad, fuzzy, weakly held powder patterns produced by near-surface discontinuities, it is essential to observe carefully the formation of indications while the powder is being applied and also while the excess is being removed. Sufficient time for indication formation and examination should be allowed between successive magnetization cycles.

15.2 *Wet Particle Application* — Wet magnetic particles, fluorescent or nonfluorescent, suspended in a vehicle at a recommended concentration may be applied either by spraying or flowing over the areas to be inspected during the application of the magnetizing field current (continuous technique) or after turning off the current (residual technique). Proper sequencing of operation (part magnetization and timing of bath application) is essential to indication formation and retention. For the continuous technique multiple current shots should be applied. The last shot should be applied after the particle flow has been diverted and while the particle bath is still on the part. A single shot may be sufficient. Care should be taken to prevent damage to a part due to overheating or other causes. Since fine or weakly held indications on highly finished or polished surfaces may be washed away or obliterated, care must be taken to prevent high-velocity flow over critical surfaces and to cut off the bath application before removing the magnetic field. Since a residual field has a lower intensity than a continuous field, less pronounced indications tend to form.

15.3 *Magnetic Slurry/Paints* — Magnetic slurry/paints are applied to the part with a brush before or during part magnetization. Indications appear as a dark line against a light silvery background. Magnetic slurry is ideal for overhead or underwater magnetic particle examination.

15.4 *Magnetic Polymers* — Magnetic polymers are applied to the test part as a liquid polymer suspension. The part is then magnetized, the polymer is allowed to cure, and the elastic coating is removed from the test surface for examination. Care must be exercised to ensure that magnetization is completed within the active migration period of the polymer which is usually about 10 min. This method is particularly applicable to areas of limited visual access such as bolt holes. Detailed application and

use instructions of the manufacturer should be followed for optimum results.

16. Interpretation of Indications

16.1 *Valid Indications* — All valid indications formed by magnetic particle examination are the result of magnetic leakage fields. Indications may be relevant (16.1.1), nonrelevant (16.1.2), or false (16.1.3).

16.1.1 *Relevant Indications* — Relevant indications are produced by leakage fields which are the result of discontinuities. Relevant indications require evaluation with regard to the acceptance standards agreed upon between the manufacturer/test agency and the purchaser (see Annex A1).

16.1.2 *Nonrelevant Indications* — Nonrelevant indications can occur singly or in patterns as a result of leakage fields created by conditions that require no evaluation such as changes in section (like keyways and drilled holes), inherent material properties (like the edge of a bimetallic weld), magnetic writing, etc.

16.1.3 *False Indications* — False indications are not the result of magnetic forces. Examples are particles held mechanically or by gravity in shallow depressions or particles held by rust or scale on the surface.

17. Recording of Indications

17.1 *Means of Recording* — When required by a written procedure, permanent records of the location, type, direction, length(s), and spacing(s) of indications may be made by one or more of the following means.

17.1.1 *Sketches* — Sketching the indication(s) and their locations.

17.1.2 *Transfer (Dry Powder Only)* — Covering the indication(s) with transparent adhesive-backed tape, removing the tape with the magnetic particle indication(s) adhering to it, and placing it on paper or other appropriate background material indicating locations.

17.1.3 *Strippable Film (Dry Powder Only)* — Covering the indication(s) with a spray-on strippable film that fixes the indication(s) in place. When the film is stripped from the part, the magnetic particle indication(s) adhere to it.

17.1.4 *Photographing* — Photographing the indications themselves, the tape, or the strippable film reproductions of the indications.

17.1.5 *Written Records* — Recording the location, length, orientation, and number of indications.

17.2 *Accompanying Information* — A record of the procedure parameters listed below as applicable should accompany the inspection results:

17.2.1 *Method Used* — Magnetic particle method (dry, wet, fluorescent, etc.).

17.2.2 *Magnetizing Technique* — Magnetizing technique (continuous, true-continuous, residual).

17.2.3 *Current Type* — Magnetizing current (AC, half-wave rectified or full-wave rectified AC, etc.).

17.2.4 *Field Direction* — Direction of magnetic field (prod placement, cable wrap sequence, etc.).

17.2.5 *Field Strength* — Magnetic current strength [ampere turns, amperes per millimetre (inch) of prod spacing, lifting force, etc.].

18. Demagnetization

18.1 *Applicability* — All ferromagnetic material will retain some residual magnetism, the strength of which is dependent on the retentivity of the part. Residual magnetism does not affect the mechanical properties of the part. However, a residual field may cause chips, filing, scale, etc. to adhere to the surface affecting subsequent machining operations, painting, or plating. Additionally, if the part will be used in locations near sensitive instruments, high residual fields could affect the operation of these instruments. Furthermore, a strong residual magnetic field in a part to be arc welded could interfere with welding. Residual fields may also interfere with later magnetic particle examination. Demagnetization is required only if specified in the drawings, specification, or purchase order. When required, an acceptable level of residual magnetization and the measuring method shall also be specified. See 18.3.

18.2 *Demagnetization Methods* — The ease of demagnetization is dependent on the coercive force of the metal. High retentivity is not necessarily related to high coercive force in that the strength of the residual field is not always an indicator of ease of demagnetizing. In general, demagnetization is accomplished by subjecting the part to a field equal to or greater than that used to magnetize the part and in nearly the same direction, then continuously reversing the field direction while gradually decreasing it to zero.

18.2.1 *Withdrawal from Alternating Current Coil* — The fastest and most simple technique is to pass the part through a high intensity alternating current coil and then slowly withdraw the part from the field of the coil. A coil of 5000 to 10 000 ampere turns is recommended. Line frequency is usually from 50 to 60 Hz alternating current. The piece should enter the coil from a 12-in. (300-mm) distance and move through it steadily and slowly until the piece is at least 36 in. (900 mm) beyond the coil. Care should be exercised to ensure that the part

is entirely removed from the influence of the coil before the demagnetizing force is discontinued, otherwise the demagnetizer may have the reverse effect of magnetizing the part. This should be repeated as necessary to reduce the residual field to an acceptable level. See 18.3. Small parts of complex figuration can be rotated and tumbled while passing through the field of the coil.

18.2.2 *Decreasing Alternating Current* — An alternative technique for part demagnetization is subjecting the part to the field while gradually reducing its strength to a desired level.

18.2.3 *Demagnetizing With Yokes* — Alternating current yokes may be used for local demagnetization by placing the poles on the surface, moving them around the area, and slowly withdrawing the yoke while it is still energized.

18.2.4 *Reversing Direct Current* — The part to be demagnetized is subjected to consecutive steps of reversed and reduced direct current magnetization to a desired level. (This is the most effective process of demagnetizing large parts in which the alternating current field has insufficient penetration to remove the internal residual magnetization.) This technique requires special equipment for reversing the current while simultaneously reducing it in small increments.

18.3 *Extent of Demagnetization* — The effectiveness of the demagnetizing operation can be indicated by the use of appropriate magnetic field indicators or field strength meters. **Caution:** A part may retain a strong residual field after having been circularly magnetized and exhibit little or no external evidence of this field. Therefore, the circular magnetization should be conducted before longitudinal magnetization if complete demagnetization is required.

18.3.1 After demagnetization residual fields should not exceed 3 G (240 Am^{-1}) anywhere in the piece, absolute value, unless otherwise agreed upon or as specified on the engineering drawing or in the contract, purchase order, or specification.

19. Post Examination Cleaning

19.1 *Particle Removal* — Post-test cleaning is necessary where magnetic particle material(s) could interfere with subsequent processing or with service requirements. The purchaser should specify when post-test cleaning is needed and the extent required.

19.2 *Means of Particle Removal* — Typical post-test cleaning techniques employed are: (a) the use of compressed air to blow off unwanted dry magnetic particles; (b) drying of wet particles and subsequent removal by brushing or with compressed air; (c) removal of wet particles by flushing with solvent; and (d) other suitable post-examination cleaning techniques may be used if they will not interfere with subsequent requirements.

20. Evaluation of System Performance/Sensitivity

20.1 *Contributing Factors* — The overall performance/sensitivity of a magnetic particle examination system is dependent upon the following:

20.1.1 Operator capability, if a manual operation is involved.

20.1.2 Control of process steps.

20.1.3 The particles or suspension, or both.

20.1.4 The equipment.

20.1.5 Visible light level.

20.1.6 Black light monitoring where applicable.

20.1.7 Magnetic field strength.

20.1.8 Field direction of orientation.

20.1.9 Residual field strength.

20.1.10 These factors should all be controlled individually.

20.2 *Maintenance and Calibration of Equipment* — The magnetic particle equipment employed should be maintained in proper working order at all times. The frequency of verification calibration, usually every six months, see Table 2, or whenever a malfunction is suspected, should be specified in the written procedures of the testing facility. Records of the checks and results provide useful information for quality control purposes and should be maintained. In addition, any or all of the tests described should be performed whenever a malfunction of the system is suspected. Calibration tests should be conducted in accordance with the specifications or documents that are applicable.

20.3 *Equipment Checks* — The following tests are recommended for ensuring the accuracy of magnetic particle magnetizing equipment.

20.3.1 *Ammeter Accuracy* — The equipment meter readings should be compared to those of a control test meter incorporating a shunt or current transformer connected to monitor the output current. The accuracy of the entire control test meter arrangement should be verified at six-month intervals or as agreed upon between the purchaser and supplier by a means traceable to the National Institute of Standards and Technology (NIST). Comparative readings shall be taken at a minimum of three output levels encompassing the usable range. The equipment meter reading shall not deviate by more than

TABLE 2
RECOMMENDED VERIFICATION INTERVALS

Item	Maximum Time Between Verifications[A]	Reference Paragraphs
Lighting:		
Visible light intensity	1 week	7.1.1
Black light intensity	1 week	7.1.2
Background visible light intensity	1 week	7.1.1
System performance using test piece or ring specimen of Fig. 18	1 day	20.8.3
Wet particle concentration	8 h. or every shift change	20.6
Wet particle contamination	1 week	20.6.4
Water break test	1 day	20.7.3
Equipment calibration/check:		
Ammeter accuracy	6 months	20.3.1
Timer control	6 months	20.3.2
Quick break	6 months	20.3.3
Dead weight check	6 months	20.3.6
Light meter checks	6 months	20.4

[A] NOTE — The maximum time between verifications may be extended when substantiated by actual technical stability/reliability data.

±10% of full scale relative to the actual current values as shown by the test meter. **Caution:** When measuring half-wave rectified AC, the direct current reading of a conventional DC test meter reading must be doubled.

20.3.2 *Timer Control Check* — On equipment utilizing a timer to control the duration of the current flow, the timer should be checked for accuracy as specified in Table 2 or whenever a malfunction is suspected.

20.3.3 *Magnetic Field Quick Break Check* — On equipment that has a quick break feature, the functioning of this circuit should be checked and verified. This test may be performed using a suitable oscilloscope or a simple test device usually available from the manufacturer. On electronic power packs or machines, failure to achieve indication of a "quick break" would indicate that a malfunction exists in the energizing circuit.

20.3.4 *Equipment Current Output Check* — To ensure the continued accuracy of the equipment, ammeter readings at each transformer tap should be made with a calibrated ammeter-shunt combination. This accessory is placed in series with the contacts. The equipment shunt should not be used to check the machine of which it is a part. For infinite current control units (non-tap switch), settings at 500-A intervals should be used. Variations exceeding ±10% from the equipment ammeter readings indicate the equipment needs service or repair.

20.3.5 *Internal Short Circuit Check* — Magnetic particle equipment should be checked periodically for internal short circuiting. With the equipment set for maximum amperage output, any deflection of the ammeter when the current is activated with no conductor between the contacts is an indication of an internal short circuit.

TABLE 3
MINIMUM YOKE LIFTING FORCE

Type Current	Yoke Pole Leg Spacing 50 to 100 mm (2 to 4 in.)	Yoke Pole Leg Spacing 100 to 150 mm (4 to 6 in.)
AC	45 N (10 lb)	
DC	135 N (30 lb)	225 N (50 lb)

20.3.6 *Electromagnetic Yoke Lifting Force Test* — The magnetizing force of a yoke (or a permanent magnet) should be tested by determining its lifting power on a steel plate. See Table 3. The lifting force relates to the electromagnetic strength of the yoke.

20.3.7 *Powder Blower* — The performance of powder blowers used to apply the dry magnetic particles should be checked at routine intervals or whenever a malfunction is suspected. The check should be made on a representative test part. The blower should coat the area under test with a light, uniform dust-like coating of dry magnetic particles and have sufficient force to remove the excess particles without disturbing those particles that are evidence of indications. Necessary adjustments to the blower's flow rate or air velocity should be made in accordance with the manufacturer's recommendations.

20.4 *Examination Area Light Level Control:*

20.4.1 *Visible Light Intensity* — Light intensity in the examination area should be checked at specified intervals with the designated light meter at the surface of the parts being examined. See Table 2.

20.4.2 *Black (ultraviolet) Light Intensity* — Black light intensity and wavelength should be checked at the specified intervals but not to exceed one-week intervals and whenever a bulb is changed. Reflectors and filters should be cleaned daily and checked for integrity. See Table 2. Cracked or broken UV filters shall be replaced immediately. Defective bulbs which radiate UV energy must also be replaced before further use.

20.5 *Dry Particle Quality Control Tests* — In order to assure uniform and consistent performance from the dry magnetic powder selected for use, it is advisable that all incoming powders be certified or tested for conformance with quality control standards established between the user and supplier.

20.5.1 *Contamination:*

20.5.1.1 *Degradation Factors* — Dry magnetic particles are generally very rugged and perform with a

high degree of consistency over a wide process envelope. Their performance, however, is susceptible to degradation from such contaminants as moisture, grease, oil, rust and mill scale particles, nonmagnetic particles such as foundry sand, and excessive heat. These contaminants will usually manifest themselves in the form of particle color change and particle agglomeration, the degree of which will determine further use of the powder. Overheated dry particles can lose their color, thereby reducing the color contrast with the part and thus hinder part examination. Particle agglomeration can reduce particle mobility during processing, and large particle agglomerates may not be retained at an indication.

20.5.1.2 *Ensuring Particle Quality* — To ensure against deleterious effects from possible contaminants, it is recommended that a routine performance/sensitivity test be conducted (see 20.8.3).

20.6 *Wet Particle Quality Control Tests* — The following tests for wet magnetic particle suspensions should be conducted at startup and at regular intervals to assure consistent performance. See Table 2. Since bath contamination will occur as the bath is used, monitoring the working bath at regular intervals is essential.

20.6.1 *Determining Bath Concentration* — Bath concentration and sometimes bath contamination are determined by measuring its settling volume through the use of a Test Method D 96 pear-shaped centrifuge tube with a 1-mL stem (0.05-mL divisions) for fluorescent particle suspensions or a 1.5-mL stem (0.1-mL divisions) for nonfluorescent suspensions. Before sampling, the suspension should be run through the recirculating system for at least 30 min to ensure thorough mixing of all particles which could have settled on the sump screen and along the sides or bottom of the tank. Take a 100-mL portion of the suspension from the hose or nozzle, demagnetize and allow it to settle for approximately 60 min with petroleum distillate suspensions or 30 min with water-based suspensions before reading. The volume settling out at the bottom of the tube is indicative of the particle concentration in the bath.

20.6.2 *Sample Interpretation* — If the bath concentration is low in particle content, add a sufficient amount of particle materials to obtain the desired concentration; if the suspension is high in particle content, add sufficient vehicle to obtain the desired concentration. If the settled particles appear to be loose agglomerates rather than a solid layer, take a second sample. If still agglomerated, the particles may have become magnetized; replace the suspension.

20.6.3 *Settling Volumes* — For fluorescent particles, the recommended settling volume (see 8.4.6) is from 0.1 to 0.4 mL in a 100-mL bath sample and from 1.2 to 2.4 mL per 100 mL of vehicle for nonfluorescent particles unless otherwise specified by the particle manufacturer.

20.6.4 *Bath Contamination* — Both fluorescent and nonfluorescent suspensions should be checked periodically for contaminants such as dirt, scale, oil, lint, loose fluorescent pigment, water (in the case of oil suspensions), and particle agglomerates which can adversely affect the performance of the magnetic particle examination process. See Table 2.

20.6.4.1 *Carrier Contamination* — For fluorescent baths, the liquid directly above the precipitate should be examined with black light. The liquid will have a little fluorescence. Its color can be compared with a freshly made-up sample using the same materials or with an unused sample from the original bath that was retained for this purpose. If the "used" sample is noticeably more fluorescent than the comparison standard, the bath should be replaced.

20.6.4.2 *Particle Contamination* — The graduated portion of the tube should be examined under black light if the bath is fluorescent and under visible light (for both fluorescent and nonfluorescent particles) for striations or bands, differences in color or appearance. Bands or striations may indicate contamination. If the total volume of the contaminates, including bands or striations exceeds 30% of the volume of magnetic particles, or if the liquid is noticeably fluorescent (see 20.6.4.1), the bath should be replaced.

20.6.5 *Particle Durability* — The durability of both the fluorescent and nonfluorescent magnetic particles in suspension should be checked periodically to ensure that the particles have not degraded due to chemical attack from the suspending oil or conditioned water vehicles or mechanically degraded by the rotational forces of the recirculating pump in a wet horizontal magnetic particle unit. Fluorescent magnetic particle breakdown in particular can result in a decrease in sensitivity and an increase in nonmagnetic fluorescent background. Lost fluorescent pigment can produce false indications that can interfere with the examination process.

20.6.6 *Fluorescent Brightness* — It is important that the brightness of fluorescent magnetic particle powder be maintained at the established level so that indication and background brightness can be kept at a relatively constant level. Variations in contrast can noticeably affect test results. Lack of adequate contrast is generally caused by:

20.6.6.1 An increase in contamination level of the vehicle increasing background fluorescence, or

20.6.6.2 Loss of vehicle because of evaporation, increasing concentration, or

20.6.6.3 Degradation of fluorescent particles. A change in contrast ratio can be observed by using a test ring specimen with an etched surface.

20.6.7 *Performance/Sensitivity* — Failure to find a known discontinuity in a part or obtain the specified indications on the test ring (see 20.8.3) indicates a need for changing of the entire bath. If a part was used, it must have been ultrasonically cleaned so that no fluorescent background can be detected when viewed under black light with a surface intensity of at least 100 $\mu W/cm^2$. If any background is noted that interferes with either detection or interpretation, the bath should be drained and a new suspension made.

20.7 *Bath Characteristics Control:*

20.7.1 *Viscosity* — The viscosity of the suspension should not exceed 5 mm^2/s (5.0 cSt), at any temperature at which the bath may be used, when tested in accordance with Test Method D 445.

20.7.2 *Flash Point* — The flash point of wet magnetic particle light petroleum distillate suspension should be a minimum of 200°F (93°C); use Test Method D 93.

20.7.3 *Water Break Test for Conditioned Water Vehicles* — Properly conditioned water will provide proper wetting, particle dispersion, and corrosion protection. The water break test should be performed by flooding a part, similar in surface finish to those under test, with suspension, and then noting the appearance of the surface of the part after the flooding is stopped. If the film of suspension is continuous and even all over the part, sufficient wetting agent is present. If the film of suspension breaks, exposing bare surfaces of the part, and the suspension forms many separate droplets on the surface, more wetting agent is needed or the part has not been sufficiently cleaned.

20.7.4 *pH of Conditioned Water Vehicles* — The pH of the conditioned water bath should be between 6.0 and 10.5 as determined by a suitable pH meter or special pH paper.

20.8 *Verifying System Performance*

20.8.1 *Production Test Parts with Discontinuities* — A practical way to evaluate the performance and sensitivity of the dry or wet magnetic particles or overall system performance, or both, is to use representative test parts with known discontinuities of the type and severity normally encountered during actual production inspection. However, the usefulness of such parts is limited because the orientation and magnitude of the discontinuities cannot be controlled. The use of flawed parts with gross discontinuities is not recommended. **Caution** — If such parts are used, they must be thoroughly cleaned and demagnetized after each use.

20.8.2 *Fabricated Test Parts with Discontinuities* — Often, production test parts with known discontinuities of the type and severity needed for evaluation are not available. As an alternative, fabricated test specimens with discontinuities of varying degree and severity can be used to provide an indication of the effectiveness of the dry or wet magnetic particle examination process.

20.8.3 *Test Plate* — The magnetic particle system performance test plate shown in Fig. 18 is useful for testing overall performance of systems using prods and yokes.

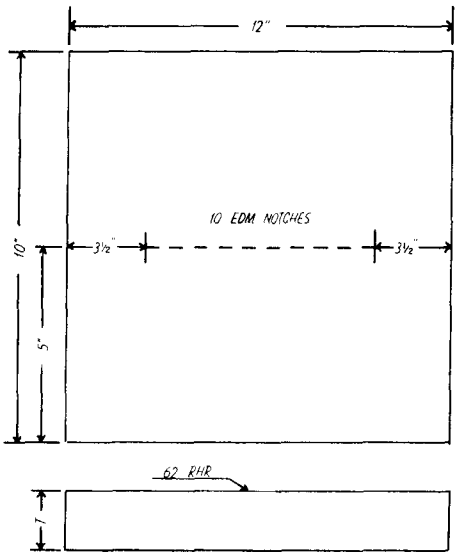
20.8.4 *Test Ring Specimen* — The test (Ketos) ring specimen (Fig. 19) is also used in evaluating and comparing the overall performance and sensitivity of both dry and wet, fluorescent and nonfluorescent magnetic particle techniques using a central conductor magnetization technique.

20.8.4.1 *Test Ring Material* — The tool steel (Ketos) ring should be machined from AISI 01 material in accordance with Fig. 19. Either the machined ring or the steel blank should be annealed at 1650°F (900°C), cooled 50°F (28°C) per hour to 1000°F (540°C) and then air cooled to ambient temperature to give comparable results using similar rings that have had the same treatment. Material and heat treatment are important variables. Experience indicates controlling the softness of the ring by hardness (90 to 95 HRB) alone is insufficient.

20.8.4.2 *Using the Test Ring* — The test ring, Fig. 19, is circularly magnetized with full-wave rectified AC passing through a central conductor with a 1 to $1\frac{1}{4}$-in. (25 to 31-mm) diameter hole located in the ring center. The conductor should have a length greater than 16 in. (400 mm). The current used, unless otherwise agreed upon by the user and the particle manufacturer, shall be 1400 amps. For dry particles the minimum number of holes shown shall be four. For wet particles the minimum number of holes shown shall be three. The ring edge should be examined after 1 min with either black light or visible light, see 20.4 depending on the type of particles involved.

20.8.5 *Magnetic Field Indicators:*

20.8.5.1 *"Pie" Field Indicator* — The magnetic field indicator shown in Fig. 15 relies on the slots between the pie shaped segments to show the presence and the approximate direction of the magnetic field. A suitable field strength is indicated when a clearly defined line of magnetic particles forms across the copper face of the



NOTE 1—EDM = Electronic Discharge Machine.
NOTE 2—RHR = Roughness Height Rating.
NOTE 3—Material should be the same type as material to be tested (a low-alloy steel plate is suitable for all low-alloy steel material to be tested).
NOTE 4—*T* should be within ±¼ in. of material to be tested up to ¾ in. *T* = ¾ in. for material ¾ in. and over.
NOTE 5—Ten notches are cut by the EDM process and are ⅛ in. (3 mm) long, 5 through 50 mils deep and 5 ± 1 mil wide.
NOTE 6—Notches are to be filled flush to the surface with a nonconducting material, such as epoxy, to prevent the mechanical holding of the indicating medium.

FIG. 18 MAGNETIC PARTICLE SYSTEM PERFORMANCE TEST PLATE

indicator (the slots are against the piece) when the magnetic particles are applied simultaneously with the magnetizing force. Failure to obtain an indication can result from: (*1*) insufficient magnetic field, or (2) the magnetic properties of the material being examined, or both.

20.8.5.2 *Slotted Shims* — Several types of slotted shims exist. Three, shown in Fig. 16, similar but not identical, have been used by the Japanese for a number of years and are being manufactured in the United States. Slot depths of 15, 30, and 60% of the shim thickness can be obtained; the slots being chemically milled. The slotted side is placed in close contact with the piece. The linear (bar) slot is useful when discontinuities are critical in a specific direction. The circular slot indicates the direction of maximum field strength and the angular tolerance of sensitivity. It can be used for developing multidirectional magnetizing procedures. The radially slotted strip has been found most useful for parts with narrow spaces and small radii. The true continuous method (10.1.2) of magnetization must be used, that is, the particles must be applied before the current flow is stopped. For dry powder applications, the excess powder must be blown off before the current stops flowing.

20.8.6 *Half-effect Probe* — The Hall-effect probe or sensor measures the tangential field strength (in air adjacent to the part) of the magnetizing force (H) and is calibrated in gauss. The sensor must be used with care. It must be kept close to the part surface. The manufacturer's instructions should be followed. These instruments can be used to detect a residual field or measure fields produced during head shots and shots using a central conductor.

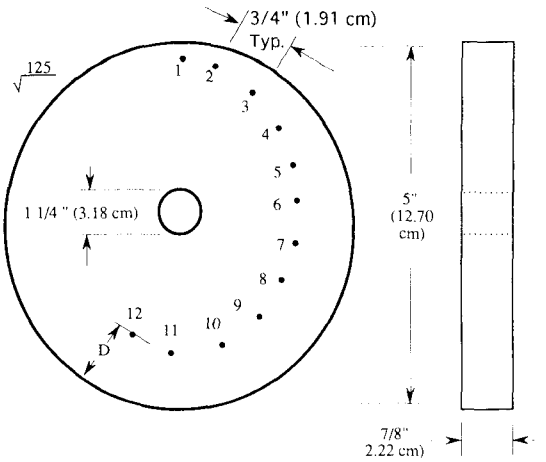
21. Procedures

21.1 When specified a procedure should be written for all magnetic particle examinations and should include as a minimum the following information. A sketch is usually used for illustrating part geometry, techniques, and areas for examination. This sketch may also be used for recording location of magnetic field indicators and for recording location of discontinuities.

21.1.1 Area to be examined (entire part or specific area),

21.1.2 Type of magnetic particle material (dry or wet, visible or fluorescent),

21.1.3 Magnetic particle equipment,



Hole	1	2	3	4	5	6	7	8	9	10	11	12
Diameter (Note 1)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)	0.07 (0.18 cm)
"D" (Note 2)	0.07 (0.18 cm)	0.14 (0.36 cm)	0.21 (0.53 cm)	0.28 (0.71 cm)	0.35 (0.90 cm)	0.42 (1.08 cm)	0.49 (1.26 cm)	0.56 (1.44 cm)	0.63 (1.62 cm)	0.70 (1.80 cm)	0.77 (1.98 cm)	0.84 (2.16 cm)

NOTE 1—All hole diameters are ±0.005 in. (±0.01 cm). Hole numbers 8 thru 12 are optional.

NOTE 2—Tolerance on the D distance is ±0.005 in. (±0.01).

NOTE 3—All dimensions are±0.03 in. (±0.08) or as noted in 1 and 2.

NOTE 4—All dimension are in inches, except as noted.

NOTE 5—Material is ANSI 01 tool steel from annealed round stock.

NOTE 6—The ring may be heat treated as follows: Heat to 1400 to 1450°F (760 to 790°C) Hold at this temperature for one hour. Cool to a maximum rate of 40°F/h (22°C/h) to below 1000°F (540°C). Furnace or air cool to room temperature. Finish the ring to RMS 25 and protect from corrosion.

FIG. 19 TEST RING

21.1.4 Part surface preparation requirements,

21.1.5 Magnetizing process (continuous, true-continuous, residual),

21.1.6 Magnetizing current (alternating, half-wave rectified AC, full-wave rectified AC, direct),

21.1.7 Means of establishing part magnetization (direct-prods, head/tailstock contact or cable wrap, indirect-coil/cable wrap, yoke, central conductor, and so forth),

21.1.8 Direction of magnetic field (circular or longitudinal),

21.1.9 System performance/sensitivity checks,

21.1.10 Magnetic field strength (ampere turns, field density, magnetizing force, and number and duration of application of magnetizing current),

21.1.11 Application of examination media,

21.1.12 Interpretation and evaluation of indications,

21.1.13 Type of records including accept/reject criteria,

21.1.14 Demagnetizing techniques, if required, and

21.1.15 Post-examination cleaning, if required,

21.2 *Written Reports* — Written reports shall be prepared as agreed upon between the testing agency/ department and the purchaser/user.

22. Acceptance Standards

22.1 The acceptability of parts examined by this method is not specified herein. Acceptance standards are a matter of agreement between the manufacturer and the purchaser and should be stated in a referenced contract, specification, or code.

23. Safety

23.1 Those involved with hands-on magnetic particle examination exposure to hazards include:

23.1.1 *Electric Shock and Burns* — Electric short circuits can cause shock and particularly burns from the high amperages at relatively low voltages that are used.

Equipment handling water suspensions should have good electrical grounds.

23.1.2 *Flying Particles* — Magnetic particles, particularly the dry ones, dirt, foundry sand, rust, and mill scale can enter the eyes and ears when they are blown off the part when applying them to a vertical or overhead surface or when cleaning an examined surface with compressed air. Dry particles are easy to inhale and the use of a dust respirator is recommended.

23.1.3 *Falls* — A fall from a scaffold or ladder if working on a large structure in the field or shop.

23.1.4 *Fire* — Ignition of a petroleum distillate bath.

23.1.5 *Environment* — Doing magnetic particle examination where flammable vapors are present as in a petrochemical plant or oil refinery. Underwater work has its own set of hazards.

23.1.6 *Wet Floors* — Slipping on a floor wetted with a particle suspension.

23.1.7 *Shifting or Dropping of Large Components* — Large components, especially those on temporary supports, can shift during examination or fall while being lifted. In addition, operators should be alert to the possibility of injury to body members being caught beneath a sling/chain or between head/tail stock and the piece.

23.1.8 *Ultraviolet Light Exposure* — Ultraviolet light in excess of 1000 $\mu W/cm^2$ can adversely affect the eyes and skin. Safety goggles designed to absorb UV wavelength radiation are suggested where high intensity blacklight is used.

23.1.9 *Materials and Concentrates* — The safe handling of magnetic particles and concentrates are governed by the supplier's Material Safety Data Sheets (MSDS). The MSDS conforming to 29 CFR 1910.1200 or equivalent must be provided by the supplier to any user and must be prepared in accordance with FED-STD-313.

24. Precision and Bias

24.1 The methodology described in the practice will produce repeatable results provided:

24.1.1 The strength of the magnetic flux field in the part/piece is confirmed and,

24.1.2 The field has the proper orientation with respect to the discontinuities being sought.

24.2 It must be recognized that the surface condition of the material being examined, the material's magnetic properties, its shape, and control of the factors listed in 20.1 influence the results obtained.

25. Keywords

25.1 dye; evaluation; examination; fluorescent; inspection; magnetic particle; nondestructive; testing

ANNEX

(Mandatory Information)

A1. TYPICAL MAGNETIC PARTICLE INDICATIONS

A1.1 Surface discontinuities with few exceptions produce sharp and distinct magnetic particle indications. Near-surface discontinuities on the other hand produce less distinct or fuzzy magnetic particle indications in comparison to surface discontinuities; the magnetic particle indications are broad rather than sharp and the particles are less tightly held.

A1.2 *Wet Method:*

A1.2.1 *Fluorescent* — Indications of surface cracks, surface indications, and an indication of a near surface discontinuity are shown in Figs. A1.1 through A1.6.

A1.2.2 *Nonfluorescent* — Indications of surface cracks are shown in Figs. A1.7 through A1.16.

A1.3 *Dry Method* — Indications of surface cracks are shown in Figs. A1.17 through A1.23.

A1.4 Nonrelevant indications are shown in Figs. A1.24 through A1.26.

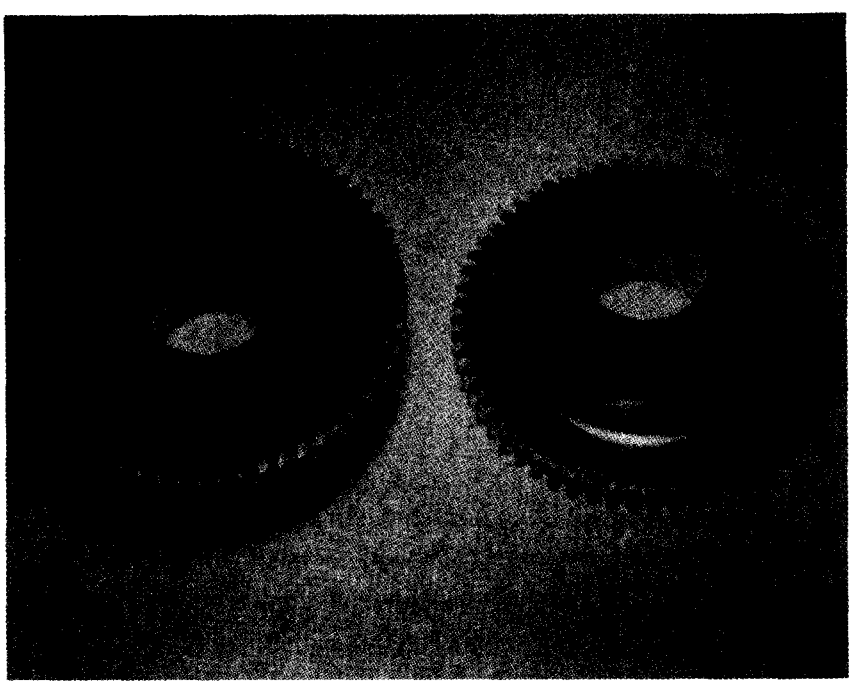


FIG. A1.1 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CENTRAL CONDUCTOR DC MAGNETIZATION)

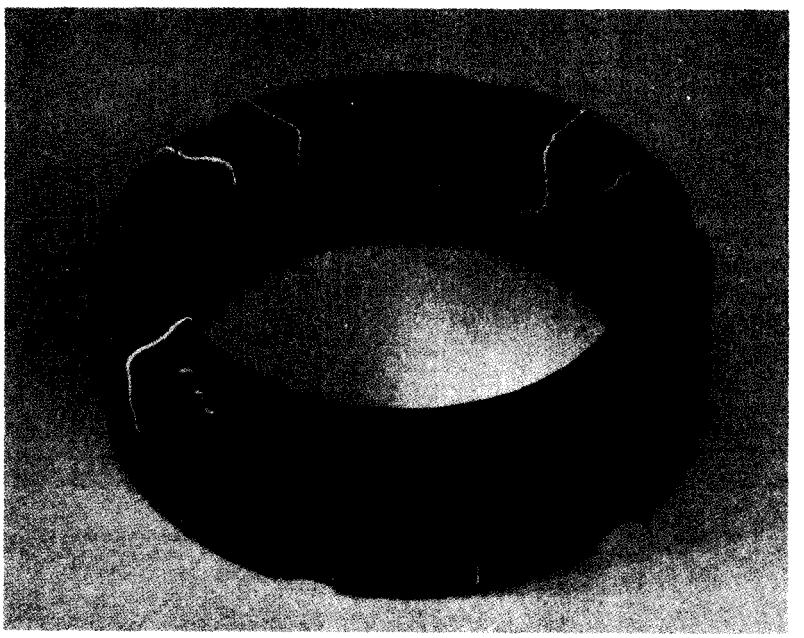


FIG. A1.2 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CENTRAL CONDUCTOR DC MAGNETIZATION)

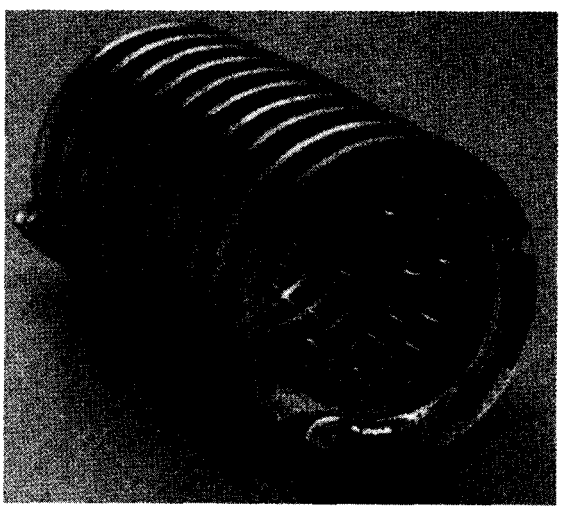


FIG. A1.3 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CENTRAL CONDUCTOR,
DC MAGNETIZATION)

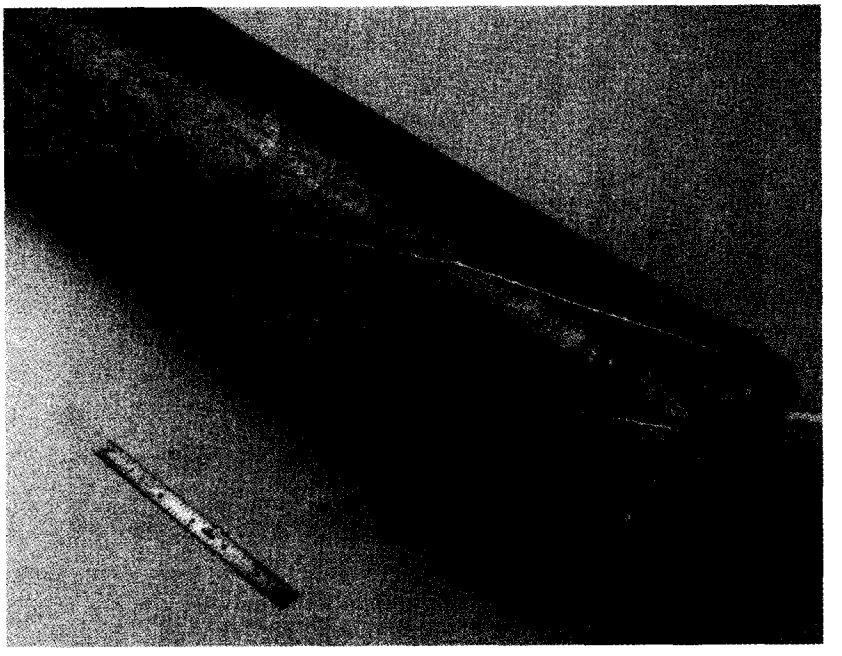


FIG. A1.4 SURFACE INDICATIONS
(PRODUCED BY CENTRAL CONDUCTOR
DC MAGNETIZATION)

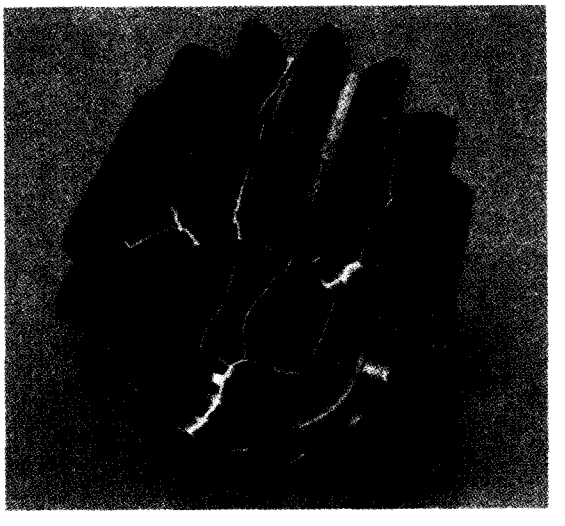


FIG. A1.5 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CIRCULAR MAGNETIZATION,
DC CONTINUOUS)

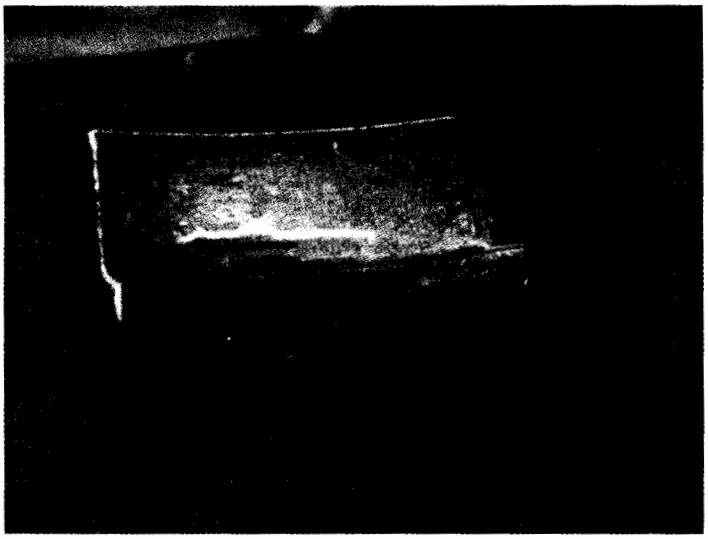


FIG. A1.6 INDICATION OF A NEAR-SURFACE DISCONTINUITY (PRODUCED BY PROD MAGNETIZATION)

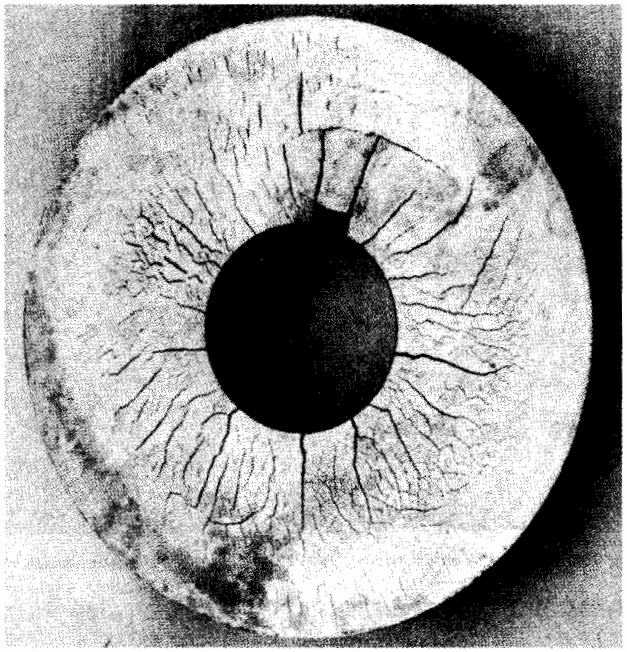


FIG. A1.7 INDICATIONS OF SURFACE CRACKING (PRODUCED BY CENTRAL CONDUCTOR MAGNETIZATION, DC CONTINUOUS)

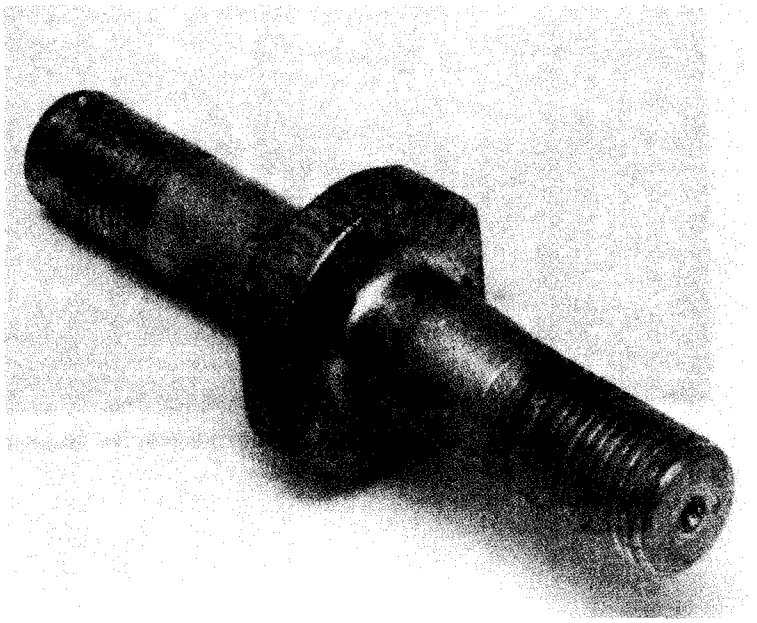


FIG. A1.8 INDICATIONS OF SURFACE CRACKING
(PRODUCED BY CIRCULAR DIRECT MAGNETIZATION,
DC CONTINUOUS)

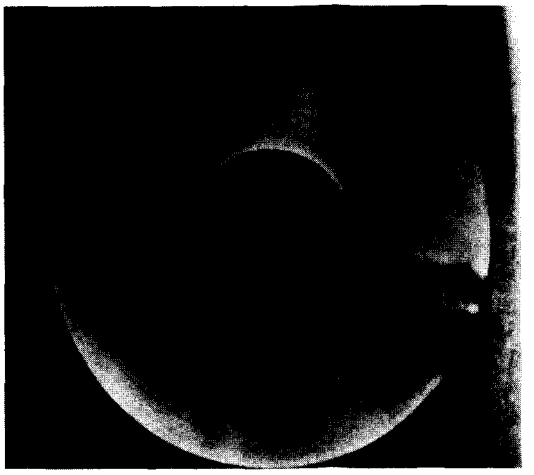


FIG. A1.9 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CENTRAL CONDUCTOR
MAGNETIZATION, DC CONTINUOUS)

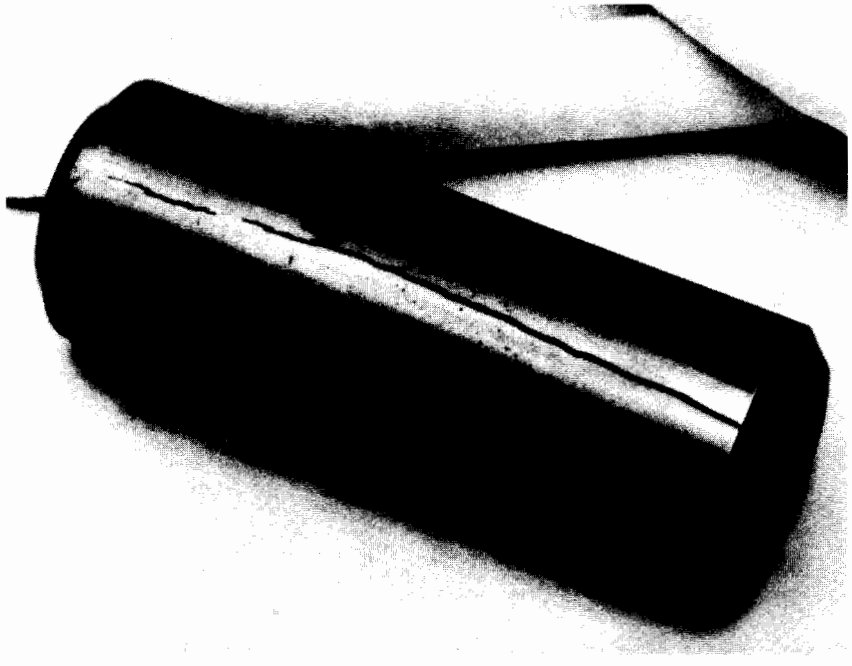


FIG. A1.10 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CIRCULAR INDIRECT MAGNETIZATION, DC)

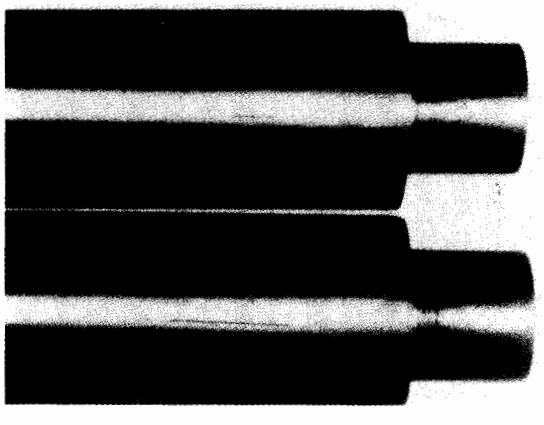


FIG. A1.11 INDICATIONS OF A NEAR-SURFACE DISCONTINUITY (PRODUCED BY CIRCULAR DIRECT MAGNETIZATION, AC CONTINUOUS)

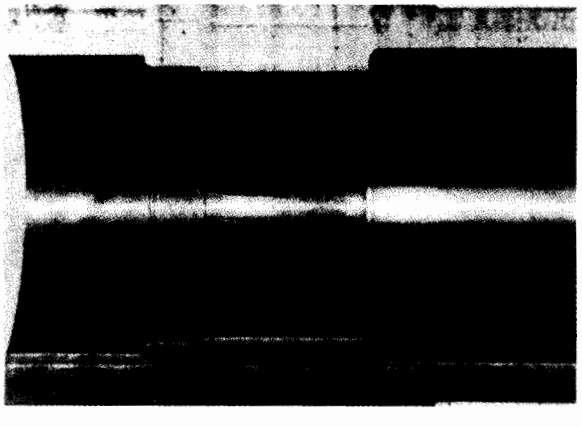


FIG. A1.12 INDICATIONS OF NEAR-SURFACE INDICATIONS (PRODUCED BY CIRCULAR DIRECT MAGNETIZATION, AC CONTINUOUS)

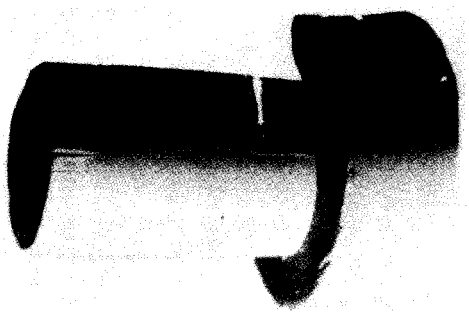


FIG. A1.13 MAGNETIC RUBBER INDICATIONS OF SURFACE CRACKS IN AIRCRAFT FASTENER HOLES (PRODUCED BY YOKE MAGNETIZATION, DC CONTINUOUS)

FIG. A1.14 MAGNETIC RUBBER INDICATIONS OF SURFACE CRACKS IN AIRCRAFT FASTENER HOLES (PRODUCED BY YOKE MAGNETIZATION, DC CONTINUOUS)

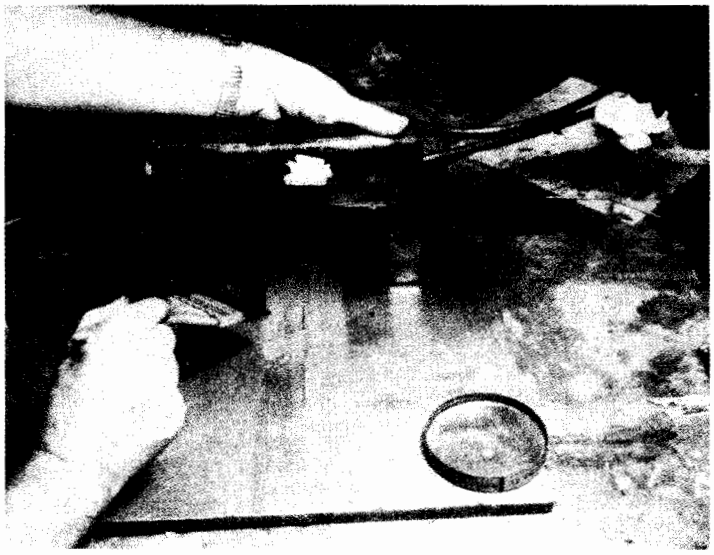


FIG. A1.15 MAGNETIC SLURRY INDICATIONS OF SURFACE CRACKS IN WELDMENT (PRODUCED BY YOKE MAGNETIZATION, AC CONTINUOUS)

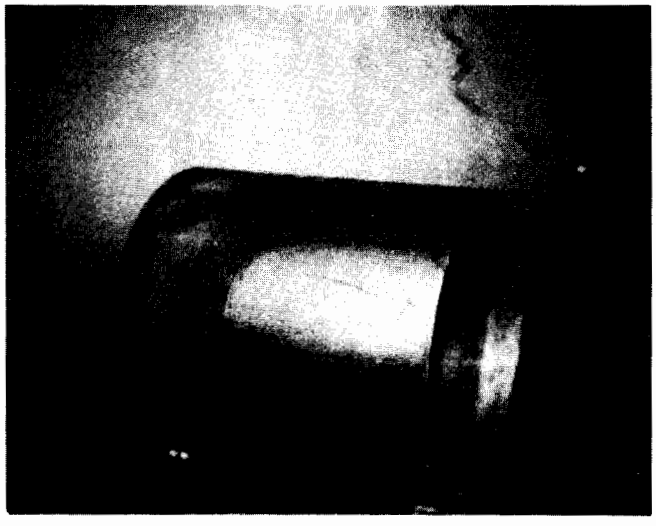


FIG. A1.16 MAGNETIC SLURRY INDICATIONS OF SURFACE CRACKS (PRODUCED BY YOKE MAGNETIZATION, AC CONTINUOUS)

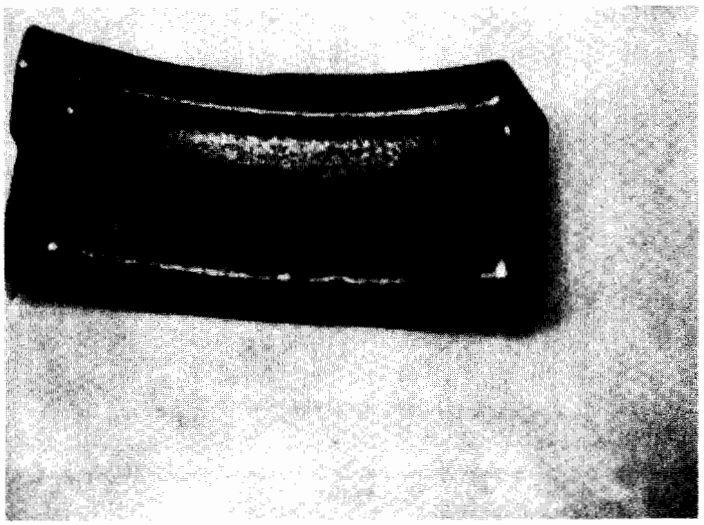


FIG. A1.17 INDICATIONS OF A NEAR-SURFACE DISCONTINUITY (PRODUCED BY PROD MAGNETIZATION, HWDC CONTINUOUS)

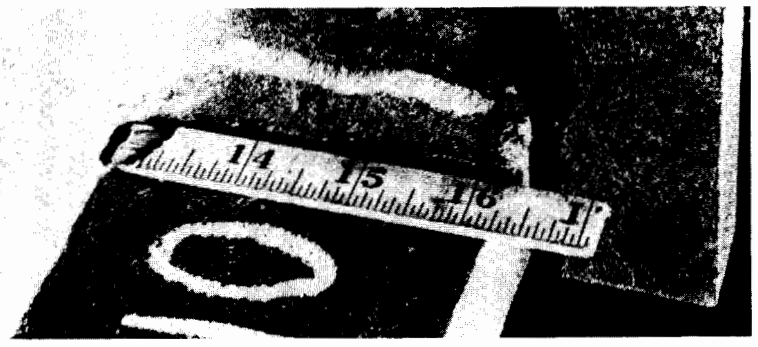


FIG. A1.18 INDICATIONS OF A NEAR-SURFACE DISCONTINUITY (PRODUCED BY PROD MAGNETIZATION, HWDC CONTINUOUS)

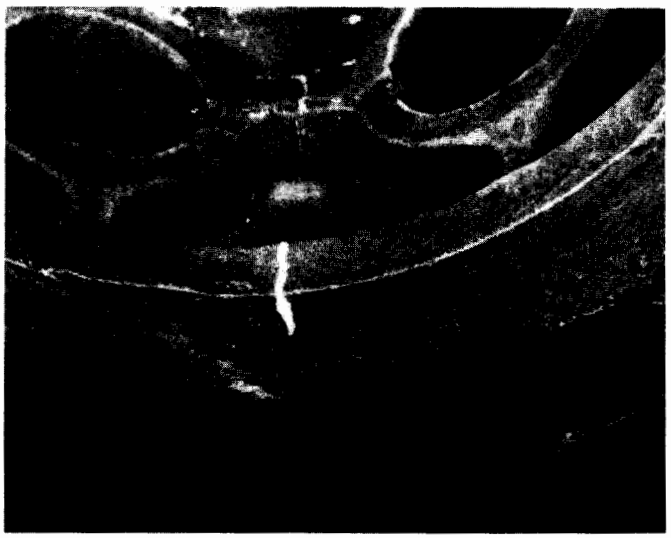


FIG. A1.19 INDICATION OF SURFACE CRACKS
(PRODUCED BY CIRCULAR INDIRECT MAGNETIZATION,
AC CONTINUOUS)

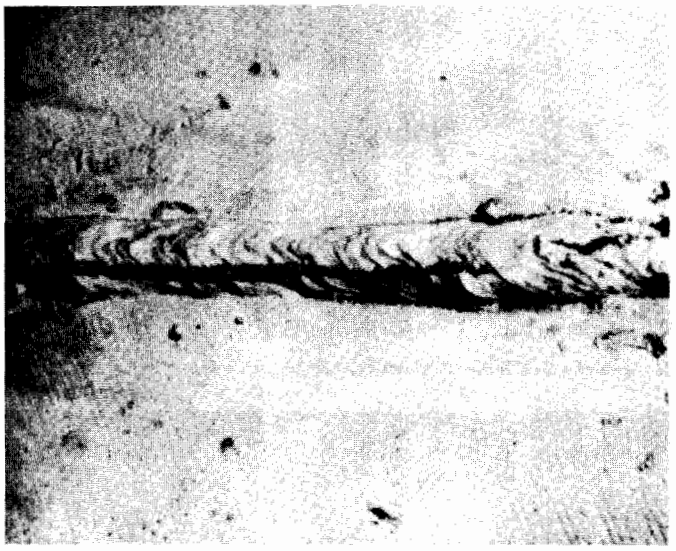


FIG. A1.20 INDICATION OF SURFACE CRACKS
(PRODUCED BY PROD MAGNETIZATION, AC CONTINUOUS)

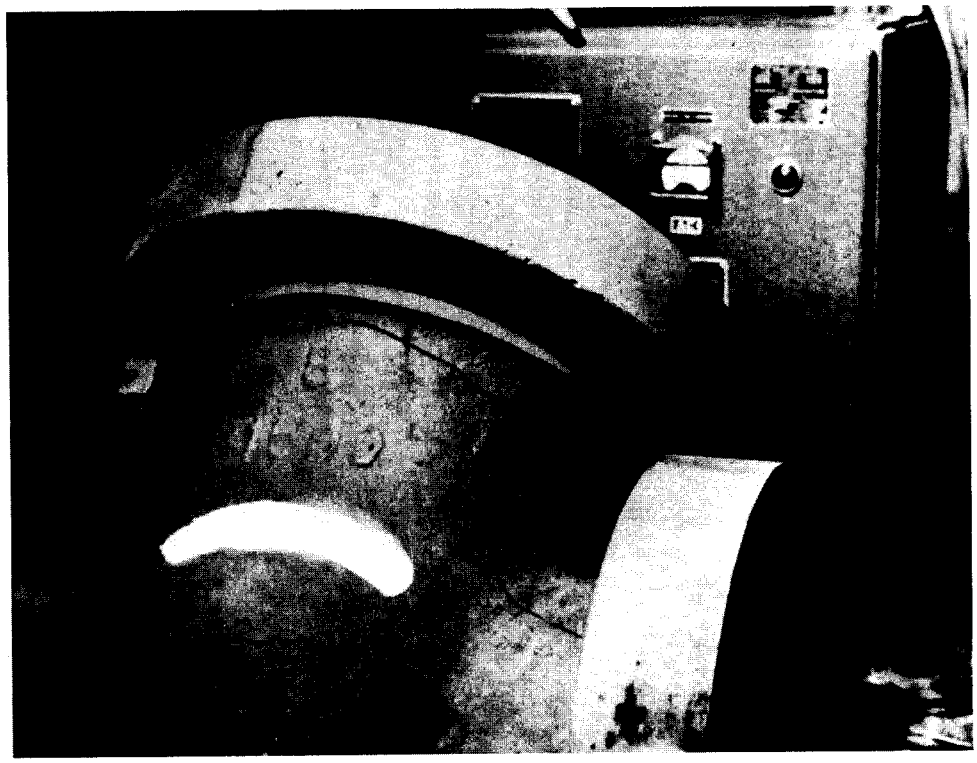


FIG. A1.21 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY PROD MAGNETIZATION,
DC CONTINUOUS)

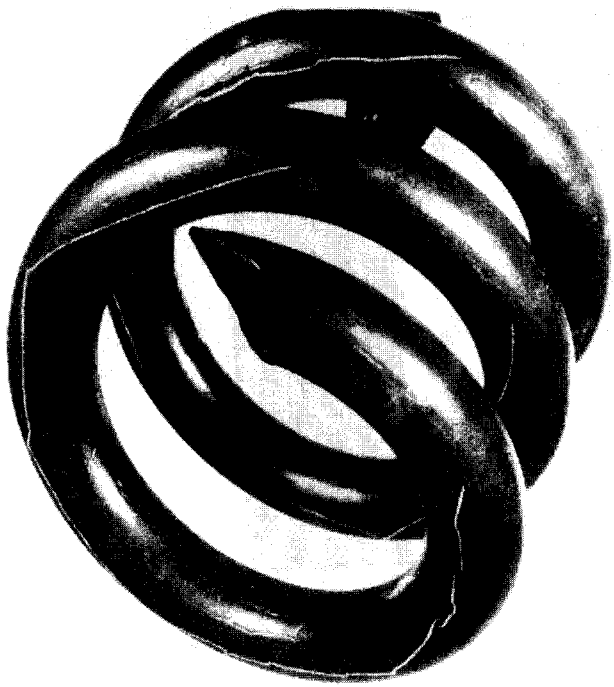


FIG. A1.22 INDICATIONS OF SURFACE CRACKS
(PRODUCED BY CIRCULAR DIRECT MAGNETIZATION,
AC CONTINUOUS)

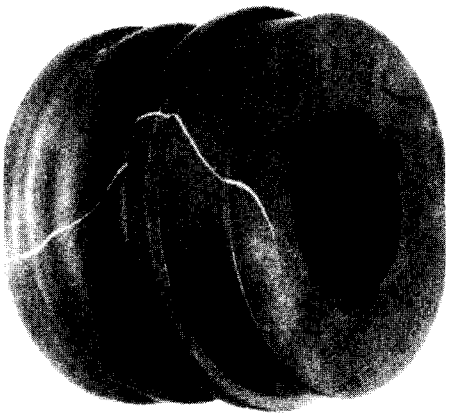


FIG. A1.23 INDICATIONS OF SURFACE CRACKS (PRODUCED BY CENTRAL CONDUCTOR MAGNETIZATION, AC CONTINUOUS)

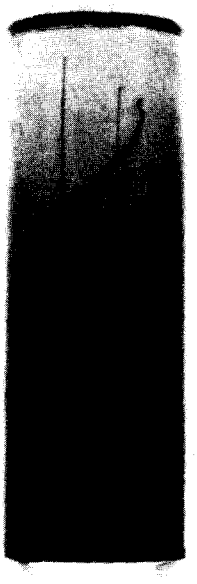


FIG. A1.24 NONRELEVANT INDICATIONS OF MAGNETIC WRITING (PRODUCED BY DIRECT MAGNETIZATION, DC CONTINUOUS)

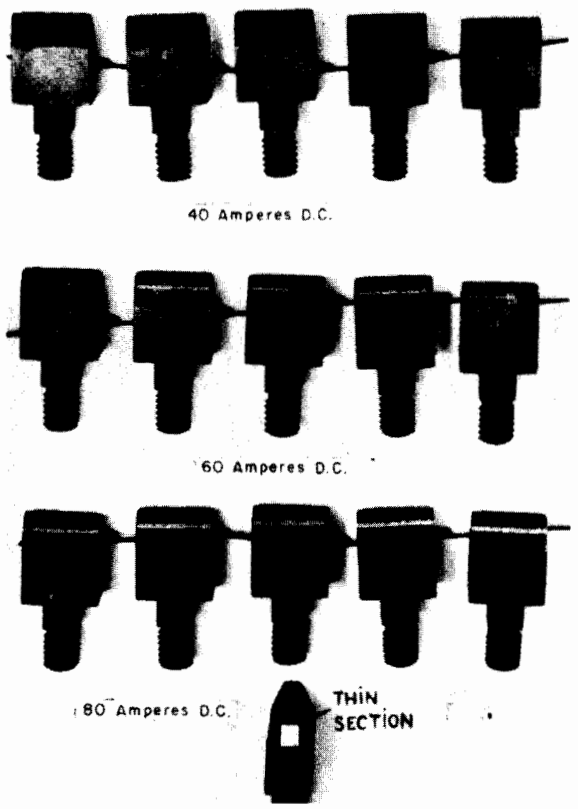


FIG. A1.25 NONRELEVANT INDICATIONS DUE TO CHANGE IN SECTION ON A SMALL PART (PRODUCED BY INDIRECT, CIRCULAR MAGNETIZATION. DC CONTINUOUS)

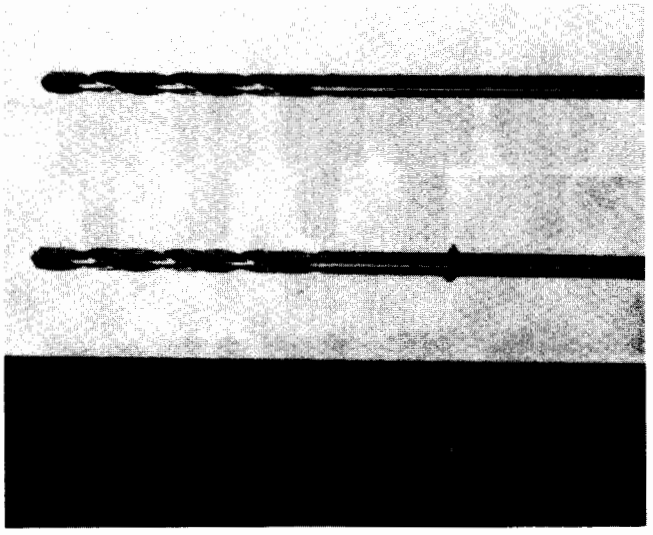


FIG. A1.26 NONRELEVANT INDICATIONS OF JUNCTION BETWEEN DISSIMILAR MATERIALS (PRODUCED BY COIL DC RESIDUAL MAGNETIZATION)

ARTICLE 26
EDDY CURRENT STANDARDS

STANDARD PRACTICE FOR ELECTROMAGNETIC (EDDY-CURRENT) EXAMINATION OF COPPER AND COPPER-ALLOY TUBES

SE-243

(Identical with ASTM Specification E 243-97)

1. Scope

1.1 This practice covers the procedures that shall be followed in eddy-current examination of copper and copper-alloy tubes for detecting discontinuities of a severity likely to cause failure of the tube. These procedures are applicable for tubes with outside diameters to $3\frac{1}{8}$ in. (79.4 mm), inclusive, and wall thicknesses from 0.017 in. (0.432 mm) to 0.120 in. (3.04 mm), inclusive, or as otherwise stated in ASTM product specifications; or by other users of this practice. These procedures may be used for tubes beyond the size range recommended, upon contractual agreement between the purchaser and the manufacturer.

1.2 The procedures described in this practice are based on methods making use of encircling annular test coil systems.

1.3 The values stated in inch-pound units are to be regarded as the standard.

NOTE 1 — This practice may be used as a guideline for the examination, by means of internal probe test coil systems, of installations using tubular products where the outer surface of the tube is not accessible. For such applications, the technical differences associated with the use of internal probe coils should be recognized and accommodated. The effect of foreign materials on the tube surface and signals due to tube supports are typical of the factors that must be considered.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 111 Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock

B 395 Specification for U-Bend Seamless Copper and Copper-Alloy Heat Exchanger and Condenser Tubes

B 543 Specification for Welded Copper and Copper-Alloy Heat Exchanger Tubes

E 543 Practice for Evaluating Agencies That Perform Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *Other Documents:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

3. Terminology

3.1 *Definitions of Terms Specific to this Standard*

3.1.1 The following terms are defined in relation to this standard.

3.1.1.1 *artificial discontinuity calibration standard* — a standard consisting of a selected tube with defined artificial discontinuities, used when adjusting the system controls to obtain some predetermined system output signal level. This standard may be used for periodic checking of the instrument during a test.

3.1.1.2 *percent maximum unbalance calibration standard* — a method of calibration that can be used with speed-insensitive instruments (see 3.1.1.4). The acceptance level of the test is established at the operating test frequency as an accurately calibrated fraction of the maximum unbalance signal resulting from the end effect of a tube. Any low-noise tube from the production run having a squared end may be used as this standard. This standard may be used for periodic checking of the instrument during a test.

3.1.1.3 *electrical center* — the center established by the electromagnetic field distribution within the test coil. A constant-intensity signal, irrespective of the circumferential position of a discontinuity, is indicative of electrical centering. The electrical center may be different from the physical center of the test coil.

3.1.1.4 *speed-sensitive equipment* — test equipment that produces a variation in signal response with variations in the test speed. Speed-insensitive equipment provides a constant signal response with changing test speeds.

3.1.1.5 *off-line testing* — eddy-current tests conducted on equipment that includes the test coil and means to propel individual tubes under test through the coil at appropriate speeds and conditions.

3.1.1.6 *on-line testing* — eddy-current tests conducted on equipment that includes the test coil and means to propel tubes under test through the coil at appropriate speeds and conditions as an integral part of a continuous tube manufacturing sequence.

3.2 *Definitions of Terms* — Refer to Terminology E 1316 for definitions of terms that are applicable to nondestructive examinations in general.

4. Summary of Practice

4.1 Testing is usually performed by passing the tube lengthwise through a coil energized with alternating current at one or more frequencies. The electrical impedance of the coil is modified by the proximity of the tube, the tube dimensions, electrical conductivity and magnetic permeability of the tube material, and metallurgical or mechanical discontinuities in the tube. During passage of the tube, the changes in electromagnetic response caused by these variables in the tube produce electrical signals which are processed so as to actuate an audio or visual signaling device or mechanical marker which produces a record.

5. Significance and Use

5.1 Eddy-current testing is a nondestructive method of locating discontinuities in a product. Signals can be produced by discontinuities located either on the external or internal surface of the tube or by discontinuities totally contained within the walls. Since the density of eddy currents decreases nearly exponentially as the distance from the external surface increases, the response to deep-seated defects decreases.

5.2 Some indications obtained by this method may not be relevant to product quality; for example, a reject signal may be caused by minute dents or tool chatter marks that are not detrimental to the end use of the product. Irrelevant indications can mask unacceptable discontinuities. Relevant indications are those which result from nonacceptable discontinuities. Any indication above the reject level that is believed to be irrelevant shall be regarded as unacceptable until it is demonstrated by reexamination or other means to be irrelevant (see 10.3.2).

5.3 Eddy-current testing systems are generally not sensitive to discontinuities adjacent to the ends of the tube (end effect). On-line eddy-current testing would not be subject to end effect.

5.4 Discontinuities such as scratches or seams that are continuous and uniform for the full length of the tube may not always be detected.

6. Basis of Application

6.1 *Personnel Qualification* — Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410, or a similar document. The practice or standard used and its applicable revision shall be specified in the purchase specification or contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Testing Agencies* — If specified in the purchase specification or contractual agreement, NDT agencies shall be evaluated and

qualified as described in Practice E 543. The applicable edition of Practice E 543 shall be identified in the purchase specification or contractual agreement between the using parties.

7. Apparatus

7.1 *Electronic Apparatus* — The electronic apparatus shall be capable of energizing the test coil with alternating currents of suitable frequencies (for example, 1 kHz to 125 kHz), and shall be capable of sensing the changes in the electromagnetic response of the coils. Electrical signals produced in this manner are processed so as to actuate an audio or visual signaling device or mechanical marker which produces a record.

7.2 *Test Coils* — Test coils shall be capable of inducing current in the tube and sensing changes in the electrical characteristics of the tube. The test coil diameter should be selected to yield the largest practical fill-factor.

7.3 *Driving Mechanism* — A mechanical means of passing the tube through the test coil with minimum vibration of the test coil or the tube. The device shall maintain the tube substantially concentric with the electrical center of the test coil. A uniform speed (±5.0% speed variation maximum) shall be maintained.

7.4 *End Effect Suppression Device* — A means capable of suppressing the signals produced at the ends of the tube. Individual ASTM product specifications shall specify when an end effect suppression device is mandatory.

NOTE 2 — Signals close to the ends of the tube may carry on beyond the limits of end suppression. Refer to 9.5.

8. Reference Standards

8.1 *Artificial Discontinuity Reference Standard:*

8.1.1 The tube used when adjusting the sensitivity setting of the apparatus shall be selected from a typical production run and shall be representative of the purchaser's order. The tubes shall be passed through the test coil with the instrument sensitivity high enough to determine the nominal background noise inherent in the tubes. The reference standard shall be selected from tubes exhibiting low background noise. For on-line eddy-current testing, the reference standard is created in a tube portion existent in the continuous manufacturing sequence or in other forms as allowed by the product specification.

8.1.2 The artificial discontinuities shall be spaced to provide signal resolution adequate for interpretation. The artificial discontinuities shall be prepared in accordance with one of the following options:

(a) A round bottom transverse notch on the outside of the tube in each of three successive transverse planes at 0, 120, and 240° (Fig. 1).

(b) A hole drilled radially through the tube wall in each of three successive transverse planes at 0, 120, and 240° (Fig. 2).

(c) One round bottom transverse notch on the outside of the tube at 0° and another at 180°, and one hole drilled radially through the wall at 90° and another at 270°. Only one notch or hole shall be made in each transverse plane (Fig. 3).

(d) Four round bottom transverse notches on the outside of the tube, all on the same element of the tube (Fig. 4).

(e) Four holes drilled radially through the tube wall, all the same element of the tube (Fig. 5).

8.1.2.1 *Round Bottom Transverse Notch* — The notch shall be made using a suitable jig with a 0.250-in. (6.35-mm) diameter No. 4 cut, straight, round file. The outside surface of the tube shall be stroked in a substantially straight line perpendicular to the axis of the tube. The notch depth shall be in accordance with the ASTM product specification or Appendix X1 if the product specification does not specify and shall not vary from the notch depth by more than ±0.0005 in. (±0.013 mm) when measured at the center of the notch (see Table X1.1).

NOTE 3 — Tables X1.1 and X1.2 should not be used for acceptance or rejection of materials.

8.1.2.2 *Drilled Holes* — The hole shall be drilled radially through the wall using a suitable drill jig that has a bushing to guide the drill, care being taken to avoid distortion of the tube while drilling. The drilled hole diameter shall be in accordance with the ASTM product specification or Appendix X1 if the product specification does not specify and shall not vary by more than +0.001, −0.000 in. (+0.026 mm) of the hole diameter specified (see Table X1.2) (Note 3).

8.1.2.3 *Other Artificial Discontinuities* — Discontinuities of other contours may be used in the reference standard by mutual agreement between supplier and purchaser.

8.2 *Percent Maximum Unbalance Reference Standard* — This method of standardization shall be used only with speed-insensitive equipment, and equipment specifically designed or adapted to accommodate the use of this calibration method. Maximum unbalance of differential coils is obtained by placing the squared end of a tube in only one of the differential coils and using an accurately calibrated attenuator to obtain the (100%) maximum unbalance signal. A percentage of the maximum unbalance signal shall define the test acceptance level at

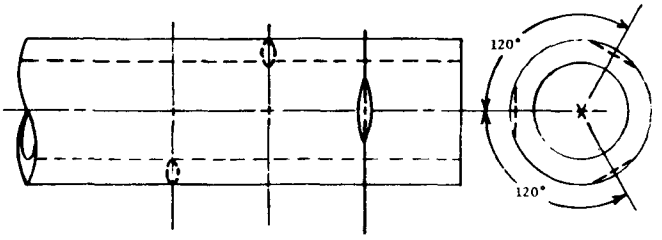


FIG. 1 REFERENCE STANDARD WITH THREE NOTCHES

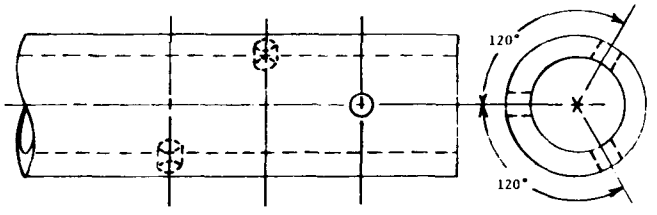
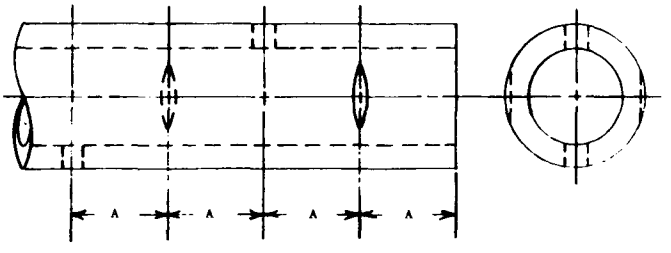
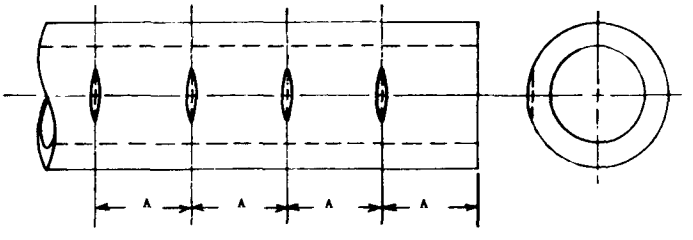


FIG. 2 REFERENCE STANDARD WITH THREE HOLES



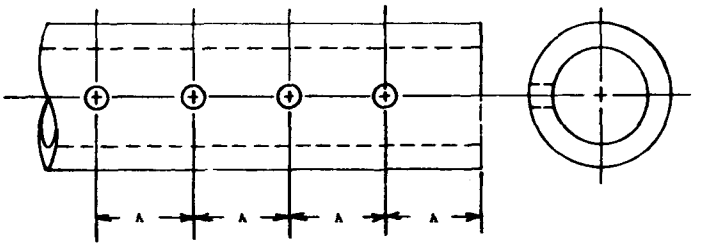
NOTE: A=Space to provide signal resolution adequate for interpretation.

FIG. 3 REFERENCE STANDARD WITH TWO NOTCHES AND TWO HOLES



NOTE: A=Space to provide signal resolution adequate for interpretation.

FIG. 4 REFERENCE STANDARD WITH FOUR NOTCHES IN LINE



NOTE: A—Space to provide signal resolution adequate for interpretation.

FIG. 5 REFERENCE STANDARD WITH FOUR HOLES IN LINE

a specific operating frequency and this percentage shall be obtained from the ASTM product specification.

8.3 *Other Reference Standards* — Other reference standards may be used by mutual agreement between supplier and purchaser.

NOTE 4 — Artificial discontinuities and the percent of maximum unbalance are not intended to be representative of natural discontinuities or produce a direct relationship between instrument response and discontinuity severity; they are intended only for establishing sensitivity levels as outlined in Section 9. The relationship between instrument response and discontinuity size, shape, and location is important and should be established separately, particularly as related to test frequency.

9. Adjustment and Standardization of Apparatus Sensitivity

9.1 The tube manufacturer shall select equipment, reference standard, and test parameters consistent for the product, unless otherwise agreed upon between manufacturer and purchaser.

9.2 When using the artificial discontinuity reference standard, prepared in accordance with one of the five options, adjust the apparatus to the lowest sensitivity required to detect the following:

9.2.1 For Figs. 1, 2, and 3: all artificial discontinuities in the standard. The tube speed maintained during standardization shall be the same as the speed used in production testing.

9.2.2 For Figs. 4 and 5: a minimum of two of the four artificial discontinuities as the tube is rotated by 120° intervals through 0, 120, and 240°, or by 90° intervals through 0, 90, 180, and 270° on successive passes. The tube speed maintained during standardization shall be the same as the speed used in production testing.

9.3 When using the percent maximum unbalance reference standard, adjust the apparatus to the percent unbalance called for in the ASTM product specification.

NOTE 5 — Sensitivity control settings are usually indicated by arbitrary numbers on the control panel of the testing instruments. These numerical settings differ among instruments of different types. It is, therefore, not proper to transfer numerical settings on one instrument to those of another instrument, unless the percent maximum unbalance reference standard is used. Even among instruments of the same design and from the same manufacturer, sensitivity control settings may vary. Undue emphasis on the numerical value of sensitivity control settings is not justified and shall not be used unless referenced accurately to the maximum unbalance signal.

9.4 Discard and replace the tube used as the reference standard when erroneous signals are produced from mechanical, metallurgical, or other damage to the standard.

9.5 Determine the length of tubing requiring suppression of end effect signals by selecting a tube of low background noise and making a series of reference holes or notches at 0.5-in. (12.7-mm) intervals near the end of this special tube. Pass the tube through the test coil at the production test speed with the artificial discontinuities end first, and then with the artificial discontinuities end last. Determine the distance from the tube end at which the signal response from successive discontinuities is uniform with a recording device such as a pen recorder or memory oscilloscope. Use a signal suppression method (photo relay, mechanical switches, or proximity devices are commonly used) to permit testing only when the length of tubing exhibiting uniform signals is within the test coil. The section of tube passing through the test coil during end effect suppression is not tested in accordance with 9.2 or 9.3.

9.5.1 As an option to 9.5, when a recording device is not available, the length of tubing requiring end suppression may be determined by selecting a tube of low background noise and making a reference hole or notch at 6 to 8 in. (152 to 203 mm) from the tube end. Pass the tube through the test coil at the production test speed with the artificial discontinuity end first and then with the artificial discontinuity end last. If the artificial discontinuity is not detected, another artificial discontinuity should be made further from the end. If it is detected, cut off 0.5-in. (12.7-mm) increments from the end of the tube until the artificial discontinuity is no longer detected.

The shortest distance from the end that the artificial discontinuity can be detected is that length of tube which shall require end effect signal suppression.

10. Procedure

10.1 Electrically center the tubing in the test coil at the start of the test run. The tube manufacturer may use the artificial discontinuity reference standard or prepare a separate tube for this purpose in accordance with 8.1 and 8.2. Pass the tube through the test system and mechanically adjust its position in the test coil such that the requirements of 9.2 are satisfied.

10.2 Standardize the test system at the start of the test run and at periodic intervals (for example, every 2 h) of continuous operation or whenever improper functioning of the system is suspected.

10.3 Pass the tubes through the test system standardized as described in Section 9.

10.3.1 Accept those tubes that produce output signals conforming to the limits in the applicable ASTM product specification.

10.3.2 Tubes that produce output signals not conforming to the limits in the applicable ASTM product specification may, at the option of the manufacturer, be set aside for reexamination (see 5.2). Upon reexamination, accept the tubes if the output signals are within acceptable limits (10.3.1) or demonstrated by other reexamination to be irrelevant.

10.4 Tubes may be examined at the finish size after the final anneal or heat treatment, or at the finish size prior to the final anneal or heat treatment unless otherwise agreed upon between the supplier and the purchaser.

11. Keywords

11.1 electromagnetic (eddy-current) testing; NDT; nondestructive testing; copper; tubing

APPENDIX

(Nonmandatory Information)

X1. TABLES

TABLE X1.1
NOTCH DEPTH

Tube Wall Thickness, in.	Tube Outside Diameter, in.			Tube Wall Thickness, mm	Tube Outside Diameter, mm		
	Over 1/4 to 3/4, incl	Over 3/4 to 1 1/4, incl	Over 1 1/4 to 3 1/8, incl		Over 6 to 19, incl	Over 19 to 32, incl	Over 32 to 79, incl
Over 0.017–0.032	0.005	0.006	0.007	Over 0.43–0.61	0.13	0.15	0.18
Incl 0.032–0.049	0.006	0.006	0.0075	Incl 0.81–1.3	0.15	0.15	0.19
Incl 0.049–0.083	0.007	0.0075	0.008	Incl 1.3–2.1	0.18	0.19	0.20
Incl 0.083–0.109	0.0075	0.0085	0.0095	Incl 2.1–2.8	0.19	0.22	0.24
Incl 0.109–0.120	0.009	0.009	0.011	Incl 2.8–3.0	0.23	0.23	0.28

TABLE X1.2
DIAMETER OF DRILLED HOLES

Tube Outside Diameter		Diameter of Drilled Holes		
in.	mm	in.	mm	Drill No.
1/4 to 3/4, incl	6.0 to 19.0, incl	0.025	0.635	72
Over 3/4 to 1, incl	Over 19.0 to 25, incl	0.031	0.785	68
Over 1 to 1 1/4, incl	Over 25 to 32, incl	0.036	0.915	64
Over 1 1/4 to 1 1/2, incl	Over 32 to 38, incl	0.042	1.07	58
Over 1 1/2 to 1 3/4, incl	Over 38 to 45, incl	0.046	1.17	56
Over 1 3/4 to 2, incl	Over 45 to 50, incl	0.052	1.32	55

STANDARD PRACTICE FOR IN SITU EXAMINATION OF FERROMAGNETIC HEAT-EXCHANGER TUBES USING REMOTE FIELD TESTING

A06

SE-2096

(Identical with ASTM Specification E 2096-00.)

1. Scope

1.1 This practice describes procedures to be followed during remote field examination of installed ferromagnetic heat-exchanger tubing for baseline and service-induced discontinuities.

1.2 This practice is intended for use on ferromagnetic tubes with outside diameters from 0.500 to 2.000 in. (12.70 to 50.80 mm), with wall thicknesses in the range from 0.028 to 0.134 in. (0.71 to 3.40 mm).

1.3 This practice does not establish tube acceptance criteria; the tube acceptance criteria must be specified by the using parties.

1.4 The values stated in either inch-pound units or SI units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this practice to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Agencies Performing Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *Other Documents:*

ASNT SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

Can CGSB-48.9712-95 Qualification of Nondestructive Testing Personnel, Natural Resources Canada

3. Terminology

3.1 *General* — Definitions of terms used in this practice can be found in Terminology E 1316, Section A, "Common NDT Terms," and Section C, "Electromagnetic Testing."

3.2 *Definitions:*

3.2.1 *detector, n* — one or more coils or elements used to sense or measure magnetic field; also known as a receiver.

3.2.2 *exciter, n* — a device that generates a time-varying electromagnetic field, usually a coil energized with alternating current (ac); also known as a transmitter.

3.2.3 *nominal tube, n* — a tube or tube section meeting the tubing manufacturer's specifications, with relevant properties typical of a tube being examined, used for reference in interpretation and evaluation.

3.2.4 *remote field, n* — as applied to nondestructive testing, the electromagnetic field which has been transmitted through the test object and is observable beyond the direct coupling field of the exciter.

3.2.5 *remote field testing, n* — a nondestructive test method that measures changes in the remote field to detect and characterize discontinuities.

3.2.6 *using parties, n* — the supplier and purchaser.

3.2.6.1 *Discussion* — The party carrying out the examination is referred to as the "supplier", and the party requesting the examination is referred to as the "purchaser", as required in Form and Style for ASTM Standards, October 1999. In common usage outside this practice, these parties are often referred to as the "operator" and "customer", respectively.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *flaw characterization standard, n* — a standard used in addition to the RFT system reference standard, with artificial or service-induced flaws, used for flaw characterization.

3.3.2 *nominal point, n* — a point on the phase-amplitude diagram representing data from nominal tube.

3.3.3 *phase-amplitude diagram, n* — a two-dimensional representation of detector output voltage, with angle representing phase with respect to a reference signal, and radius representing amplitude [Fig. 1, Sketches (a) and (b)].

3.3.3.1 *Discussion* — In this practice, care has been taken to use the term "phase angle" (and "phase") to refer to an angular equivalent of time displacement, as defined in Terminology E 1316. When an angle is not necessarily representative of time, the general term "angle of an indication on the phase-amplitude diagram" is used.

3.3.4 *RFT system, n* — the electronic instrumentation, probes, and all associated components and cables required for performing RFT.

3.3.5 *RFT system reference standard, n* — a reference standard with specified artificial flaws, used to set up and standardize a remote field system and to indicate flaw detection sensitivity.

3.3.6 *sample rate* — the rate at which data is digitized for display and recording, in data points per second.

3.3.7 *strip chart, n* — a diagram that plots coordinates extracted from points on a phase-amplitude diagram versus time or axial position [Fig. 1, sketch (c)].

3.3.8 *zero point, n* — a point on the phase-amplitude diagram representing zero detector output voltage.

3.3.8.1 *Discussion* — Data on the phase-amplitude diagram are plotted with respect to the zero point. The zero point is separate from the nominal point unless the detector is configured for zero output in nominal tube. The angle of a flaw indication is measured about the nominal point.

3.4 *Acronyms:*

3.4.1 RFT, n-remote field testing

4 Summary of Practices

4.1 The RFT data is collected by passing a probe through each tube. The electromagnetic field transmitted from the exciter to the detector is affected by discontinuities; by the dimensions and electromagnetic properties of the tube; and by objects in and around the tube that are ferromagnetic or conductive. System sensitivity is verified using the RFT system reference standard. System sensitivity and settings are checked and recorded prior to and at regular intervals during the examination. Data and system settings are recorded in a manner that allows archiving and later recall of all data and system settings for each tube. Interpretation and evaluation are carried out using one or more flaw characterization standards. The supplier generates a final report detailing the results of the examination.

5 Significance and Use

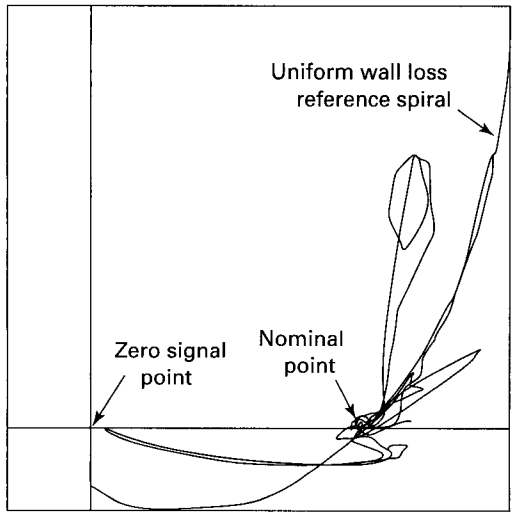
5.1 The purpose of RFT is to evaluate the condition of the tubing. The evaluation results may be used to assess the likelihood of tube failure during service, a task which is not covered in this practice.

5.2 *Principle of Probe Operation.* In a basic RFT probe, the electromagnetic field emitted by an exciter travels outwards through the tube wall, axially along the outside of tube, and back through the tube wall to a detector (Fig. 2, sketch (a)].

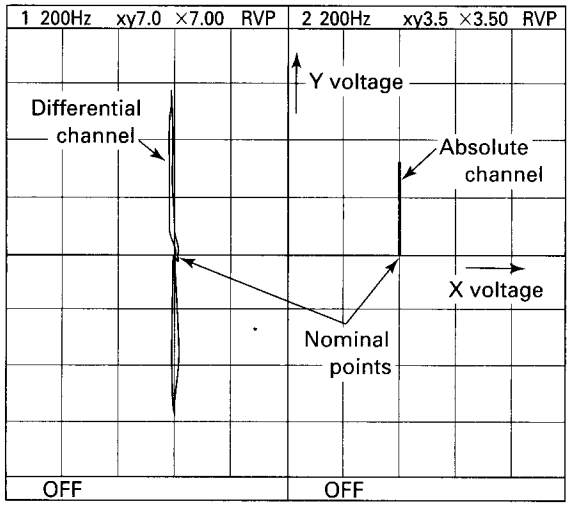
5.2.1 Flaw indications are created when (1) in thin-walled areas, the field arrives at the detector with less attenuation and less time delay, (2) discontinuities interrupt the lines of magnetic flux, which are aligned mainly axially, or (3) discontinuities interrupt the eddy currents, which flow mainly circumferentially. A discontinuity at any point on the through-transmission path can create a perturbation; thus RFT has approximately equal sensitivity to flaws on the inner and outer walls of the tube.

5.3 *Probe Configuration.* The detector is typically placed two to three tube diameters from the exciter, in a location where the remote field dominates the direct-coupling field. Other probe configurations or designs may be used to optimize flaw detection, as described in 9.3.

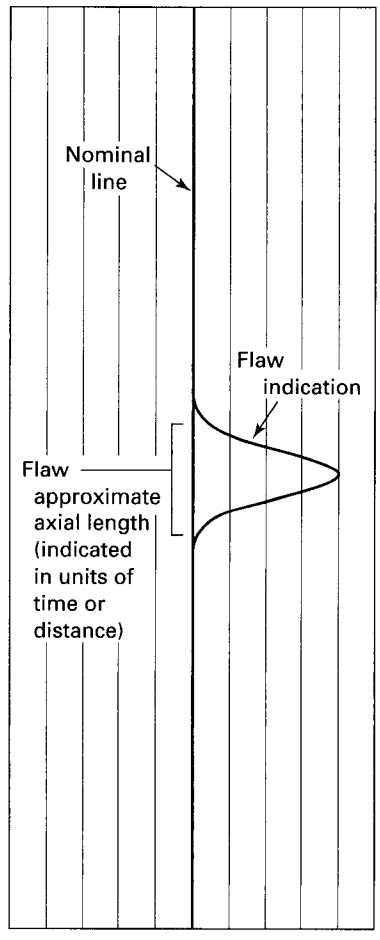
5.4 *Comparison with Conventional Eddy-Current Testing.* Conventional eddy-current test coils are typically configured to sense the field from the tube wall in the immediate vicinity of the emitting element, whereas RFT probes are typically designed to detect changes in the remote field.



(a) Typical Phase-Amplitude Diagram Used in RFT



(b) Typical Phase-Amplitude Diagram Used in RFT



(c) Generic Strip Chart With Flaw

FIG. 1

6. Basis of Application

6.1 *Personnel Qualification:*

6.1.1 Personnel performing examinations to this practice shall be qualified as specified in the contractual agreement.

6.1.2 Recommendations for qualification as an RFT system operator (Level I) are as follows:

6.1.2.1 Forty hours of RFT (Level I) classroom training.

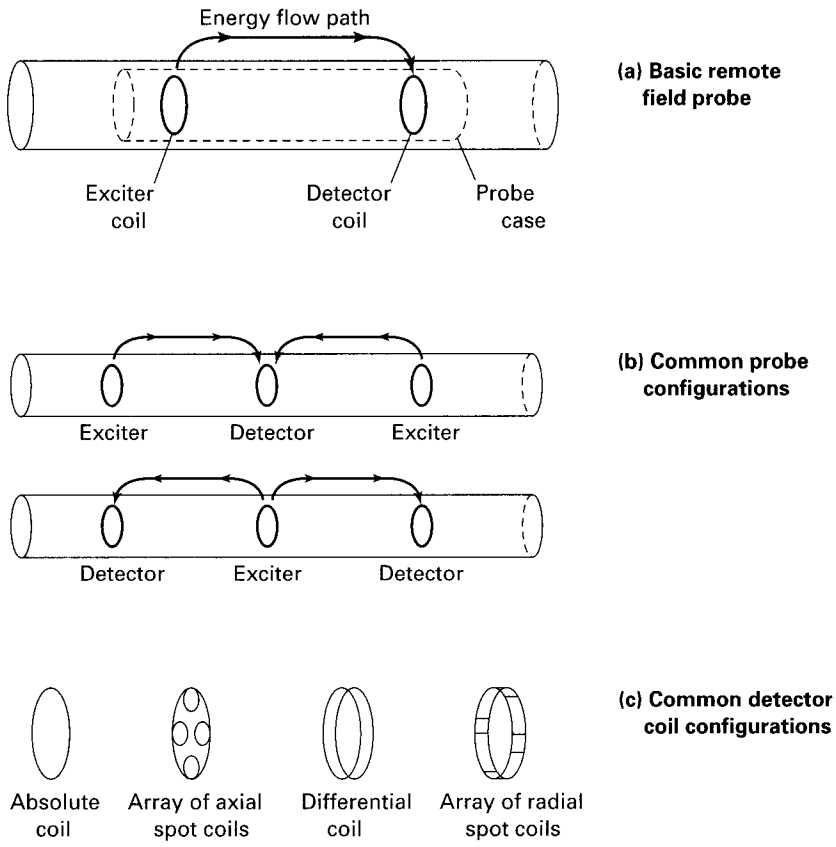
6.1.2.2 Written and practical examinations similar to those described by ASNT SNT-TC-1A or Can CGSB 48.9712-95.

6.1.2.3 Two hundred and fifty hours of field experience under the supervision of a qualified RFT Level II, 50% of which should involve RFT instrumentation setup and operation.

6.1.3 Recommendations for qualification as an RFT data analyst (Level II) are as follows:

6.1.3.1 Forty hours of RFT (Level II) classroom training.

6.1.3.2 Written and practical examinations similar to those described by ASNT SNT-TC-1A or Can CGSB 48.9712-95.



GENERAL NOTE: Arrows indicate flow of electromagnetic energy from exciter to detector. Energy flow is perpendicular to lines of magnetic flux.

FIG. 2 RFT PROBES

6.1.3.3 Fifteen hundred hours of field experience under the supervision of a qualified RFT Level II or higher, 25% of which should involve RFT data analysis.

NOTE 1: At the time of approval of this practice, no nationally or internationally recognized guideline for personnel qualification in RFT was available.

NOTE 2: Eddy-current training provides some useful background to RFT training. Previous Level II eddy-current certification may count towards 50% of training and experience hours for RFT Level I, provided that the remaining experience hours are entirely involved in RFT instrumentation setup and operation.

6.2 *Qualification of Nondestructive Testing Agencies.* If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543, with reference to sections on electromagnetic testing. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

7. Job Scope and Requirements

7.1 The following items may require agreement between the using parties and should be specified in the purchase document or elsewhere:

7.1.1 Location and type of tubed component to be examined, design specifications, degradation history, previous nondestructive examination results, maintenance history, process conditions, and specific types of flaws that are required to be detected, if known.

7.1.2 The maximum window of opportunity for work. (Detection of small flaws may require a slower probe pull speed, which will affect productivity.)

7.1.3 Size, material grade and type, and configuration of tubes to be examined.

7.1.4 A tube numbering or identification system.

7.1.5 Extent of examination, for example: complete or partial coverage, which tubes and to what length, whether straight sections only, and the minimum radius of bends that can be examined.

7.1.6 Means of access to tubes, and areas where access may be restricted.

7.1.7 Type of RFT instrument and probe; and description of reference standards used, including such details as dimensions and material.

7.1.8 Required operator qualifications and certification.

7.1.9 Required tube cleanliness.

7.1.10 Environmental conditions, equipment, and preparations that are the responsibility of the purchaser; common sources of noise that may interfere with the examination.

NOTE 3: Nearby welding activities may be a major source of interference.

7.1.11 Complementary methods or techniques (including possible tube removal) that may be used to obtain additional information.

7.1.12 Acceptance criteria to be used in evaluating flaw indications.

7.1.13 Disposition of examination records and reference standards.

7.1.14 Format and outline contents of the examination report.

8. Interferences

8.1 This section describes items and conditions which may compromise RFT.

8.2 *Material Properties*

8.2.1 Variations in the material properties of ferromagnetic tubes are a potential source of inaccuracy. Impurities, segregation, manufacturing process, grain size, stress history, present stress patterns, temperature history, present temperature, magnetic history, and other factors will affect the electromagnetic response measured during RFT. The conductivity and permeability of tubes with the same grade of material are often measurably different. It is common to find that some of the tubes to be examined are newer tubes with different material properties.

8.2.2 Permeability variations may occur at locations where there was uneven temperature or stress during tube manufacture, near welds, at bends, where there were uneven heat transfer conditions during service, at areas where there is cold working (such as that created by an integral finning process), and in other locations. Indications from permeability variations may be mistaken for, or obscure flaw indications. Effects may be less severe in tubes that were stress-relieved during manufacture.

8.2.3 Residual stress, with accompanying permeability variations, may be present when discontinuities are machined into a reference standard, or during the integral finning process.

8.2.4 The RFT is affected by residual magnetism in the tubing, including residual magnetism created during a previous examination using another magnetic method. Tubes with significant residual magnetism should be demagnetized prior to RFT.

8.3 *Ferromagnetic and Conductive Objects*

8.3.1 Objects near the tube that are ferromagnetic or conductive may reduce the sensitivity and accuracy of flaw characterization in their immediate vicinity. Such objects may in some cases be mistaken for flaws. Knowledge of the mechanical layout of the component to be examined is recommended. Examples of ferromagnetic or conductive objects include: tube support plates, baffle plates, end plates, tube sheets, anti-vibration bars, neighboring tubes, impingement plates, loose parts, and attachments clamped or welded to a tube.

NOTE 4: Interference from ferromagnetic or conductive objects can be of practical use when RFT is used to confirm the position of an object installed on a tube or to detect where objects have become detached and have fallen against a tube.

8.3.2 *Neighboring Tubes*

8.3.2.1 In areas where there is nonconstant tube spacing (bowing) or where tubes cross close to each other, there are indications which may be mistaken for flaws.

8.3.2.2 Neighboring or adjacent tubes, according to their number and position, create an offset in the phase. This phenomenon is known as the bundle effect and is a minor source of inaccuracy when absolute readings in nominal tube are required.

8.3.2.3 In cases where multiple RFT probes are used simultaneously in the same heat exchanger, care should be taken to ensure adequate spacing between different probes.

8.3.3 Conductive or magnetic debris in or on a tube that may create false indications or obscure flaw indications should be removed.

8.4 *Tube Geometry Effects*

8.4.1 Due to geometrical effects (as well as to the effects of permeability variations described in 8.2.2), localized changes in tube diameter such as dents, bulges, expansions, and bends create indications which may obscure or distort flaw indications.

8.4.2 Reductions in the internal diameter may require a smaller diameter probe that is able to pass through the restriction. In the unrestricted sections, flaw sensitivity is likely to be limited by the smaller probe fill factor.

8.4.3 RFT End Effect-The field from the exciter is able to propagate around the end of a tube when there is no shielding from a tube sheet or vessel shell. A flaw indication may be obscured or distorted if the flaw or

any active probe element is within approximately three tube diameters of the tube end.

8.5 *Instrumentation*

8.5.1 The operator should be aware of indicators of noise, saturation, or signal distortion particular to the instrument being used. Special consideration should be given to the following concerns:

8.5.1.1 In a given tube, an RFT system has a frequency where the flaw sensitivity is as high as practical without undue influence from noise.

8.5.1.2 Saturation of electronic components is a potential problem in RFT because signal amplitude increases rapidly with decreasing tube wall thickness. Data acquired under saturation conditions is not acceptable.

8.5.2 *Instrument-induced Phase Offset.* During the amplification and filtering processes, instruments may introduce a frequency-dependent time delay which appears as a constant phase offset. The instrument phase offset may be a source of error when phase values measured at different frequencies are compared.

9. RFT System

9.1 *Instrumentation.* The electronic instrumentation shall be capable of creating exciter signals of one or more frequencies appropriate to the tube material. The apparatus shall be capable of phase and amplitude analysis of detector outputs at each frequency, independent of other frequencies in use simultaneously. The instrument shall display data in real time. The instrument shall be capable of recording data and system settings in a manner that allows archiving and later recall of all data and system settings for each tube.

9.2 *Driving Mechanism.* A mechanical means of traversing the probe through the tube at approximately constant speed may be used.

9.3 *Probes.* The probes should be of the largest diameter practical for the tubes being examined, leaving clearance for debris, dents, changes in tube diameter, and other obstructions. The probes should be of an appropriate configuration and size for the tube being examined and for the flaw type or types to be detected. Probe centering is recommended.

9.3.1 *Absolute Detectors.* Absolute detectors [Fig. 2, sketch (c)] are commonly used to characterize and locate large-volume and gradual metal loss.

9.3.2 *Differential Detectors.* Differential detectors [Fig. 2, sketch (c)] are commonly used to characterize and locate large-volume and gradual metal loss, and also tend to maximize the response from small volume flaws and abrupt changes along the tube length.

9.3.3 *Array Detector.* Array detectors use a configuration of multiple sensing elements [Fig. 2, sketch (c)]. Each element is sensitive to a discrete section of the tube circumference. The elements may be oriented with their axes aligned axially or radially with respect to the tube.

NOTE 5: The detector's response represents an average of responses to all flaws within its sensing area.

9.3.4 *Exciter and Detector Configurations.* Probes may have multiple exciters and detectors in a variety of configurations [see, for example, Fig. 2, sketch (b)]. These configurations may reduce interference from support plates and other conductive objects.

9.4 *Data Displays*

9.4.1 The data display should include a phase-amplitude diagram [Fig. 1, sketch (a) and (b)].

9.4.2 *Strip Charts.* Coordinates that may be displayed on strip charts include: horizontal position, vertical position, angular position, or radial position. Angular position may represent phase. Angular position and the logarithm of radial position for an absolute detector may be linearly related to overall wall thickness.

10. RFT Tube Standards

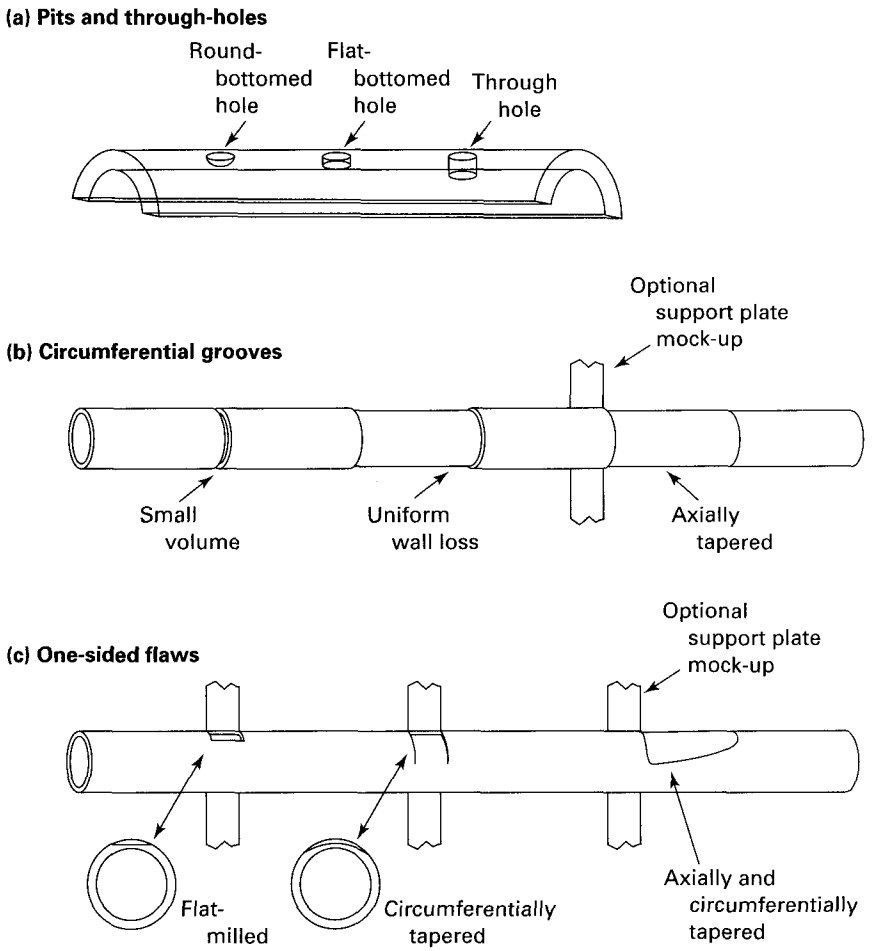
10.1 The RFT tube standards should be of the same nominal dimensions, material type, and grade as the tubes to be examined. In the case where a tube standard identical to the tubes to be examined is not available, a demonstration of examination equivalency is recommended. Allowable differences in material and dimensional variations are specified in 11.6.2.

10.2 The RFT system reference standard shall not be used for flaw characterization unless the artificial flaws can be demonstrated to be similar to the flaws detected. Allowable differences in material and dimensional variations are specified in 11.6.2.

10.2 The RFT system reference standard shall not be used for flaw characterization unless the artificial flaws can be demonstrated to be similar to the flaws detected.

10.3 *Typical Artificial Flaws in Flaw Characterization Standards*

10.3.1 *Through, Round-Bottomed, and Flat-Bottomed Holes.* Holes of different depths are used for pit characterization, and may be machined individually or in groups. Drill and milling tools of different diameters can be used to produce different flaw volumes for a given depth of metal loss (Fig. 3a).



GENERAL NOTE: Not to scale.

FIG. 3 TYPICAL ARTIFICIAL DISCONTINUITIES USED FOR FLAW CHARACTERIZATION REFERENCE STANDARDS

10.3.2 *Circumferential Grooves.* A circumferential groove is an area of metal loss whose depth at any axial location is uniform around the tube circumference. Short grooves, with a maximum axial length of less than one half a tube diameter, may be used to simulate small-volume metal loss. Grooves with an axial length of several different flaw volumes for a given depth of metal loss [Fig. 3, sketch (a)].

10.3.2 *Circumferential Grooves.* A circumferential groove is an area of metal loss whose depth at any axial location is uniform around the tube circumference. Short grooves, with a maximum axial length of less than one half a tube diameter, may be used to simulate small-volume metal loss. Grooves with an axial length of several tube diameters may be used to simulate uniform wall loss [Fig. 3, sketch (b)].

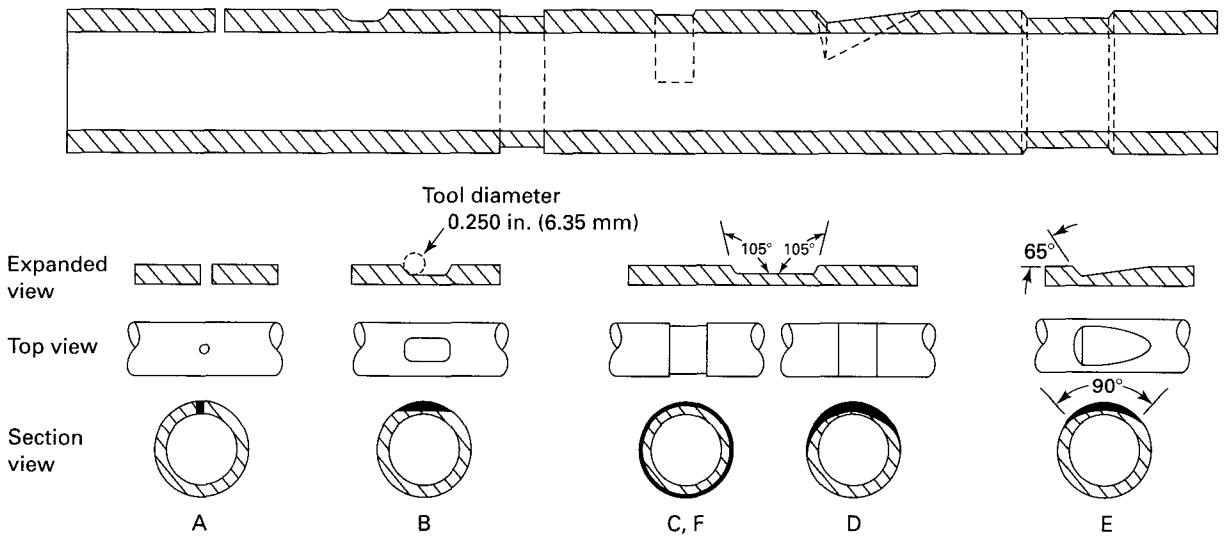
10.3.3 *One-Sided Flaws.* Metal loss is referred to as one-sided if it is predominantly on one side of a tube. Outside diameter long, flat flaws typically simulate tube-to-tube wear. Circumferentially tapered

10.4 *RFT System Reference Standards.* Flaw depths are specified by giving the deepest point of the flaw as a percentage of the measured average wall thickness. Flaw depths shall be measured and accurate to within ± 20% of the depth specified or ± 0.003 in. (± 0.08 mm), whichever is smaller. All other flaw within ± 5 deg.

10.5 *Artificial Flaws for RFT System Reference Standards:*

10.5.1 The RFT system reference standard has specific artificial flaws. It is used to set up and standardize

Flaw	A	B	C	D	E	F
% Depth	100%	50%	20%	40%	60%	20%
Flaw Type	Through-Hole	Flat	Groove	Wear Scar	Tapered flaw	Groove
Flaw Length or Diameter	K × Tube Wall thickness*	1/2 × Tube Diameter	0.625 in. (15.88 mm)	0.625 in. (15.88 mm)	4 × Tube Diameter	2 × Tube Diameter (Length optional)



GENERAL NOTES:
(a) Not to scale.
(b) For tubes of outside diameter less than 1.000 in. (25.40 mm), K = 1.
(c) For tubes of outside diameter greater than or equal to 1.000 in. (25.40 mm), K = 1.5.

FIG. 4 MANUFACTURING REFERENCE FOR RFT SYSTEM REFERENCE STANDARD

a remote field system and to indicate flaw detection sensitivity. Unless otherwise specified by the purchaser, the artificial flaws for the RFT system reference standard are as follows:

10.5.1.1 *Through-Hole.* A through-hole (Fig. 4, Flaw A) whose diameter is equal to the tube wall thickness multiplied by a specified factor. For tubes of outside diameter less than 1.000 in. (25.40 mm), the factor is 1. For tubes of outside diameter greater than or equal to 1.000 in., the factor is 1.5.

10.5.1.2 *Flat-Milled Flaw.* A flat-milled flaw (Fig. 4, Flaw B) of a depth of 50% and axial length one half the tube nominal outside diameter. The flat should be side-milled using a milling tool of a diameter of 0.250 in. (6.35 mm) to create rounded corners.

10.5.1.3 *Short Circumferential Groove.* A short circumferential groove (Fig. 4, Flaw C) of a depth of 20% and axial length of 0.625 in. (15.88 mm). Edges shall be angled at 105 deg as indicated in the insert in Fig. 4.

10.5.1.4 *Wear Scar.* A simulated wear scar from a tube support plate (Fig. 4, Flaw D), consisting of a circumferentially tapered groove, 40% deep, extending over 180 deg of the tube circumference. Axial length measured at the bottom surface of the flaw shall be 0.625 in. (15.88 mm). Edges shall be angled at 105 deg as indicated in the insert in Fig. 4.

10.5.1.5 *Tapered Flaw.* A tapered flaw simulating near-tube-support erosion (Fig. 4, Flaw E) consisting of a groove, 60% deep, tapered circumferentially, and in both directions axially. The steep side of the flaw shall be angled at 65 deg to the tube axis. The shallow side of the flaw shall be axially tapered so that it extends an axial distance of four tube diameters from the deepest point. The circumferential extent at the maximum point shall be 90 deg.

10.5.1.6 *Long Circumferential Groove.* A long circumferential groove (Fig. 4, Flaw F) of a depth of 20% and recommended axial length of two tube diameters. Length is optional according to application. Edges

shall be angled at 105 deg, as indicated in the insert in Fig. 4.

10.6 *Simulated Support Structures*

10.6.1 The RFT tube standards may have simulated support structures to represent heat exchanger bundle conditions.

10.6.2 *Support Plates.* Support plates may be simulated by drilling a single hole through a solid flat plate with a clearance of up to 0.015 in. (0.38 mm) beyond the outside diameter of the RFT tube standard. To prevent the field from propagating around the plate, the minimum distance from the edge of the tube hole to the edge of the plate should be greater than two tube diameters, unless a smaller dimension can be demonstrated to be adequate. For example, the simulated tube support plate for a 1-in. diameter tube should be at least a 5-in. (127.00-mm) square or a 5-in. diameter circle. The accuracy of the support plate simulation may be increased if the simulated plate is of the same thickness and material as the support plates in the component to be examined.

10.7 *Manufacture and Care of RFT Tube Standards*

10.7.1 *Drawings.* For each RFT tube standard, there shall be a drawing that includes the as-built measured flaw dimensions, material type and grade, and the serial number of the actual RFT tube standard.

10.7.2 *Serial Number.* Each RFT tube standard shall be identified with a unique serial number and stored so that it can be obtained and used for reference when required.

10.7.3 *Flaw Spacing.* Artificial flaws should be positioned axially to avoid overlapping of indications and interference from end effects.

10.7.4 Machining personnel shall use proper machining practices to avoid excessive cold-working, over-heating, and undue stress and permeability variations.

10.7.5 Tubes should be stored and shipped so as to prevent mechanical damage.

11. Procedure

11.1 If necessary, clean the inside of the tubes to remove obstructions and heavy ferromagnetic or conductive debris.

11.2 *Instrument Settings*

11.2.1 *Operating Frequency.* Using the appropriate RFT system reference standard, the procedures in 11.2.1.1 or 11.2.1.2 are intended to help the user select an operating frequency. Demonstrably equivalent methods may be used. If the RFT system is not capable of operating at the frequency described by this practice, the supplier shall declare to the purchaser that conditions of reduced sensitivity may exist.

11.2.1.1 Using the RFT system reference standard, and referring to the phase-amplitude diagram, set the frequency to obtain a difference of 50 to 120 deg between the angles of indication for the reference through-hole (Flaw A in Fig. 4) and a 20% circumferential groove of a axial length of 0.125 in. (3.18 mm) (as permitted for Flaw F in Fig. 4).

11.2.1.2 If phase is measured and displayed, set the frequency so that a circumferential groove with an axial length of two tube diameters (as permitted for Flaw F in Fig. 4) creates a phase shift of between 18 and 22 deg in the absolute detector output.

11.2.2 *Secondary Frequencies.* To detect and characterize some damage mechanisms, it may be necessary to use secondary frequencies to provide additional information.

11.2.3 *Pull Speed.* Determine a pull speed appropriate to the frequency, sample rate, and required sensitivity to flaws.

11.2.4 Set other instrument settings as appropriate to achieve the minimum required sensitivity to flaws.

NOTE 6: Factors which influence sensitivity to flaws include, but are not limited to: operating frequency, instrument noise, instrument filtering, digital sample rate, probe speed, coil configuration, fill factor, probe travel noise, and interferences described in Section 8.

11.3 Ensure that the system yields the minimum required sensitivity to all flaws on the RFT system reference standard at the examination pull speed. For a flaw to be considered detectable, its indication should exceed the ambient noise by a factor of at least 3, unless otherwise specified by the purchaser. An exception may be made when the purchaser requires only a large-volume metal loss examination, in which case, sensitivity should be demonstrated for specified large-volume flaws on the RFT system reference standard.

11.4 Acquire and record data from the RFT system reference standard and flaw characterization standards at the selected examination pull speed.

11.5 Acquire and record data from the tubes to be examined. Maintain as uniform a probe speed as possible throughout the examination to produce repeatable indications.

11.5.1 Record data and system settings in a manner that allows archiving and later recall of all data and system settings for each tube. Throughout the examination, data

shall be permanently recorded, unless otherwise specified by the purchaser.

11.5.2 For maintaining system consistency throughout the examination, monitor typical RFT responses from support plates and tube ends, or monitor the absolute phase in the nominal tube. If conditions change, appropriate adjustments need to be made in accordance with 11.6.

11.6 *Compensation for Material and Dimensional Differences*

11.6.1 To compensate for differences in dimensional and material properties, the system may be re-normalized where appropriate by adjusting frequency or gain, or both. To re-normalize, adjust the settings so that one of the following values remains equal in the reference standard and in a nominal examined tube:

11.6.1.1 The amplitude and angular position of a support plate indication on the phase-amplitude diagram, or

11.6.1.2 The angular difference between a support plate indication and the tube-exit indication on the phase-amplitude diagram, or

11.6.1.3 The absolute phase in the nominal tube.

NOTE 7: For an alternate method of compensating for differences in dimensional and material properties, see 11.12.

11.6.2 The frequencies used in the reference standards and in the tubes to be examined should not differ by more than a factor of two. If the factor exceeds this value, the reference standard should be considered inappropriate and replaced with one that more accurately represents the material to be tested.

11.6.3 After frequency and gain adjustments have been made, apply appropriate compensations to the examination sample rate and pull speed.

11.7 *Compensation for Ferromagnetic or Conductive Objects*

11.7.1 Techniques that may improve RFT results near interfering ferromagnetic or conductive objects include:

11.7.1.1 Comparison of baseline or previous examination data with the current examination data.

11.7.1.2 Comparison of indications from known objects with and without metal loss. (Obtain a reference indication from a typical object on or near the nominal tube or from a simulated object on a reference standard.)

11.7.1.3 The use of special probe coil configurations.

11.7.1.4 Processing of multiple-frequency signals to suppress nonrelevant indications.

11.7.1.5 The use of a complementary method or technique (see 11.12).

11.8 *System Check.* At regular intervals, carry out a system check using the RFT system reference standard to demonstrate system sensitivity and operating parameters to the satisfaction of the purchaser. Carry out a system check prior to starting the examination, after any field compensation adjustments in accordance with 11.6, at the beginning and end of each work shift, when equipment function is in doubt, after a change of personnel, after a change of any essential system components, and overall at a minimum of every four hours. If the flaw responses from the RFT system reference standard have changed substantially, the tubes examined since the last system check shall be reexamined.

11.9 *Interpret the data (identify indications)*

11.10 Note areas of limited sensitivity, using indications from the RFT system reference standard as an indicator of flaw detectability.

11.11 Using a flaw characterization standard, evaluate relevant indications in accordance with acceptance criteria specified by the purchaser.

11.11.1 A common parameter used as a flaw depth indicator is the angle of an indication on the phase-amplitude diagram. Different angle-depth calibration curves may be used according to flaw volume, as indicated by the amplitude of the indication on the phase-amplitude diagram.

11.12 If desired, examine selected areas using an appropriate complementary method or technique to obtain more information, adjusting results where appropriate.

11.13 *Compile and present a report to the purchaser.*

12. Report

12.1 The following items may be included in the examination report. All the following information should be archived, whether or not it is required in the report.

12.1.1 Owner, location, type, and serial number of component examined.

12.1.2 Size, material type and grade, and configuration of tubes examined.

12.1.3 Tube numbering system.

12.1.4 Extent of examination, for example, areas of interest, complete or partial coverage, which tubes, and to what length.

12.1.5 Personnel performing the examination and their qualifications.

12.1.6 Models, types, and serial numbers of the components of the RFT system used, including probe and extension length.

12.1.7 For the initial data acquisition from the RFT system reference standard, a complete list of all relevant instrument settings and parameters used, such as operating frequencies, probe drive voltages, gains, types of mixed or processed channels, and probe speed. The list shall enable settings to be referenced to each individual tube examined.

12.1.8 Serial numbers of all of the tube standards used.

12.1.9 Brief outline of all techniques used during the examination.

12.1.10 A list of all heat-exchanger regions or specific tubes where limited sensitivity was obtained. Indicate which flaws on the system reference standard would not have been detectable in those regions. Where possible, indicate factors that may have limited sensitivity.

12.1.11 Specific information about techniques and depth reference curves used for sizing each indication.

12.1.12 Acceptance criteria used to evaluate indications.

12.1.13 A list of flaws as specified in the purchasing agreement.

12.1.14 Complementary examination results that influenced interpretation and evaluation.

13. Keywords

13.1 eddy current; electromagnetic testing; ferromagnetic tube; remote field testing; RFT; tube; tubular products

ARTICLE 29
ACOUSTIC EMISSION STANDARDS

STANDARD GUIDE FOR MOUNTING PIEZOELECTRIC ACOUSTIC EMISSION SENSORS

SE-650

(Identical with ASTM Specification E 650-97)

1. Scope

1.1 This document provides guidelines for mounting piezoelectric acoustic emission (AE) sensors.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E 1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *bonding agent* — a couplant that physically attaches the sensor to the structure.

3.1.2 *couplant* — a material used at the structure-to-sensor interface to improve the transfer of acoustic energy across the interface.

3.1.3 *mounting fixture* — a device that holds the sensor in place on the structure to be monitored.

3.1.4 *sensor* — a detection device that transforms the particle motion produced by an elastic wave into an electrical signal.

3.1.5 *waveguide, acoustic* — a device that couples acoustic energy from a structure to a remotely mounted sensor. For example, a solid wire or rod, coupled to a sensor at one end and to the structure at the other.

3.2 *Definitions:*

3.2.1 For definitions of additional terms relating to acoustic emission, refer to Terminology E 1316.

4. Significance and Use

4.1 The methods and procedures used in mounting AE sensors can have significant effects upon the performance of those sensors. Optimum and reproducible detection of AE requires both appropriate sensor-mounting fixtures and consistent sensor-mounting procedures.

5. Mounting Methods

5.1 The purpose of the mounting method is to hold the sensor in a fixed position on a structure and to ensure that the acoustic coupling between the sensor and the structure is both adequate and constant. Mounting methods will generally fall into one of the following categories:

5.1.1 *Compression Mounts* — The compression mount holds the sensor in intimate contact with the surface of the structure through the use of force. This force

is generally supplied by springs, torqued-screw threads, magnets, tape, or elastic bands. The use of a couplant is strongly advised with a compression mount to maximize the transmission of acoustic energy through the sensor-structure interface.

5.1.2 *Bonding* — The sensor may be attached directly to the structure with a suitable adhesive. In this method, the adhesive acts as the couplant. The adhesive must be compatible with the structure, the sensor, the environment, and the test procedure.

6. Mounting Requirements

6.1 *Sensor Selection* — The correct sensors should be chosen to optimally accomplish the acoustic-emission test objective. Sensor parameters to be considered are as follows: size, sensitivity, frequency response, surface-motion response, and environmental and material compatibility. When a multichannel acoustic-emission test is being conducted, a subset of sensors with characteristics similar to each other should be selected. See Guide E 976 for methods of comparing sensor characteristics.

6.2 *Structure Preparation* — The contacting surfaces should be cleaned and mechanically prepared. This will enhance the detection of the desired acoustic waves by assuring reliable coupling of the acoustic energy from the structure to the sensor. Preparation of these surfaces must be compatible with the construction materials used in both the sensor and the structure. Possible losses in acoustic energy transmission caused by coatings such as paint, encapsulants, loose-mill scale, weld spatter, and oxides as well as losses due to surface curvature at the contact area must be considered.

6.3 *Couplant or Bonding Agent Selection:*

6.3.1 The type of couplant or bonding agent should be selected with appropriate consideration for the effects of the environment (for example, temperature, pressure, composition of gas, or liquid environment) on the couplant and the constraints of the application. It should be chemically compatible with the structure and not be a possible cause of corrosion. In some cases, it may be a requirement that the couplant be completely removable from the surface after testing. In general, the selection of the couplant is as important from an environmental standpoint as it is from the acoustical standpoint.

6.3.2 For sensors that are primarily sensitive to particle motion perpendicular to their face, the viscosity of the couplant is not an important factor. Most liquids or greases will work as a couplant if they wet the surfaces of both the structure and the sensor. For those few sensors which are sensitive primarily to motion in the plane of their face, very high viscosity couplant or a rigid bond is recommended.

6.3.3 The thickness of the couplant may alter the effective sensitivity of the sensor. The thinnest practical layer of continuous couplant is usually the best. Care should be taken that there are no entrapped voids in the couplant. Uneveness, such as a taper from one side of the sensor to the other, can also reduce sensitivity or produce an unwanted directionality in the sensor response.

6.3.4 A useful method for applying a couplant is to place a small amount of the material in the center of the sensor face, then carefully press the sensor on to the structure surface, spreading the couplant uniformly from the center to the outside of the sensor face.

6.3.5 In some applications, it may be impractical to use a couplant because of the nature of the environment (for example, very high temperatures or extreme cleanliness requirements). In these situations, a dry contact may be used, provided sufficient mechanical force is applied to hold the sensor against the structure. The necessary contact pressure must be determined experimentally. As a rough guide, this pressure should exceed 0.7 MPa (100 psi).

6.3.6 Great care must be taken when bonding a sensor to a structure. Surface deformation, which can be produced by either mechanical loading or thermal expansion, may cause a bond to crack, peel off, or, occasionally, destroy the sensor. Bond cracking is a source of acoustic emission. A compliant adhesive may work in some cases. If differential expansion between the sensor, the bond, and the surface is a possibility, a suitable bonding agent should be confirmed by experiment.

6.3.7 When bonds are used, the possibility of damaging either the sensor or the surface of the structure during sensor removal must be considered.

6.3.8 The use of double-sided adhesive tape as a bonding agent is not recommended.

6.4 *Mounting Fixture Selection:*

6.4.1 Mounting fixtures must be constructed so that they do not create extraneous acoustic emission or mask valid acoustic emission generated in the structure being monitored.

6.4.1.1 The mount must not contain any loose parts or particles.

6.4.1.2 Permanent mounting may require special techniques to prevent sensor movement caused by environmental changes.

6.4.1.3 Detection of surface waves may be suppressed if the sensor is enclosed by a welded-on fixture

or located at the bottom of a threaded hole. The mounting fixture should always be designed so that it does not block out a significant amount of acoustic energy from any direction of interest.

6.4.2 The mounting fixture should provide support for the signal cable to prevent the cable from stressing the sensor or the electrical connectors. In the absence of a mounting fixture, some form of cable support should be provided. Care should be taken to ensure that the cable can neither vibrate nor be moved easily. False signals may be generated by the cable striking the structure and by triboelectric effects produced by cable movement.

6.4.3 Where necessary, protection from the environment should be provided for the sensor or sensor and mounting fixture.

6.4.4 The mounting fixture should not affect the integrity of the structure being monitored.

6.4.4.1 Permanently installed mounting fixtures must be constructed of a material compatible with the structure. Possible electrolytic effects or other forms of corrosion must be considered when designing the mounting fixture.

6.4.4.2 Alterations of the local environment by the mount, such as removal of the insulation, must be carefully evaluated and corrected if necessary.

6.4.5 The mounting fixture should be designed to have a minimal effect on the response characteristics of the sensor.

6.5 *Waveguides* — When adverse environments make direct contact between the sensor and the structure undesirable, an acoustic waveguide may be used to convey the acoustic signal from the structure to the sensor. The use of a waveguide inserts another interface with its associated losses between the structure and the sensor and will distort, to some degree, the characteristics of the acoustic wave.

6.5.1 An acoustic waveguide should be mounted so as to ensure that its surface will not contact any materials that will cause signal damping in the waveguide.

6.5.2 If acoustic waveguides are used when acoustic-emission source location is being performed, the extra time delay in the waveguides must be accounted for in the source location program.

7. Verification of Response

7.1 After the sensor(s) are mounted on a structure, adequate response should be verified by injecting acoustic signals into the structure and examining the detected signal either on an oscilloscope or with the AE system to be used in the test. If there is any doubt as to the sensor response, the sensor should be remounted.

7.1.1 The test signal may be injected by an external source such as the Hsu-pencil source, or a gas jet (helium or other suitable gas), or by applying an electrical pulse to another sensor mounted on the structure. For a description of these methods see Guide E 976.

7.2 *Periodic Verification* — On an extended acoustic emission test, it may be desirable to verify the response of the sensors during the test. Verification should be performed whenever circumstances indicate the possibility of a change in the coupling efficiency.

7.3 *Post Verification* — At the end of an acoustic emission test, it is good practice to verify that all sensors are still working and that there have been no dramatic changes in coupling efficiencies.

8. Report

8.1 Any report of the mounting practice should include details of the sensor mounting fixture(s), surface preparation method, and the couplant that was used.

9. Keywords

9.1 acoustic emission; acoustic emission sensors; acoustic emission transducers; AE; bonding agent; couplant; mounting fixture; waveguide

STANDARD GUIDE FOR DETERMINING THE REPRODUCIBILITY OF ACOUSTIC EMISSION SENSOR RESPONSE

SE-976.2

(Identical with ASTM Specification E 976-00)

1. Scope

1.1 This guide defines simple economical procedures for testing or comparing the performance of acoustic emission sensors. These procedures allow the user to check for degradation of a sensor or to select sets of sensors with nearly identical performances. The procedures are not capable of providing an absolute calibration of the sensor nor do they assure transferability of data sets between organizations.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 Acoustic emission data is affected by several characteristics of the instrumentation. The most obvious of these is the system sensitivity. Of all the parameters and components contributing to the sensitivity, the acoustic emission sensor is the one most subject to variation. This variation can be a result of damage or aging, or there can be variations between nominally identical sensors. To detect such variations, it is desirable to have a method for measuring the response of a sensor to an acoustic wave. Specific purposes for checking sensors include: *(1)* checking the stability of its response with time; *(2)* checking the sensor for possible damage after accident or abuse; *(3)* comparing a number of sensors for use in a multichannel system to ensure that their responses are adequately matched; and *(4)* checking the response after thermal cycling or exposure to a hostile environment. It is very important that the sensor characteristics be always measured with the same sensor cable length and impedance as well as the same preamplifier or equivalent. This guide presents several procedures for measuring sensor response. Some of these procedures require a minimum of special equipment.

3. Principles of Application

3.1 The procedures given in this guide are designed to measure the response of an acoustic emission sensor to an arbitrary but repeatable acoustic wave. These procedures in *no* way constitute a calibration of the sensor. The absolute calibration of a sensor requires a complete knowledge of the characteristics of the acoustic wave exciting the sensor or a previously calibrated reference sensor. In either case, such a calibration is beyond the scope of this guide.

3.2 The fundamental requirement for comparing sensor responses is a source of repeatable acoustic waves. The characteristics of the wave do not need to be known as long as the wave can be reproduced at will. The sources and geometries given in this guide will produce primarily compressional waves. While the sensors will respond differently to different types of waves, changes in the response to one type of wave will imply changes in the responses to other types of waves.

3.3 These procedures all use a test block or rod. Such a device provides a convenient mounting surface for the sensor and when appropriately marked, can ensure that the source and the sensor are always positioned identically with respect to each other. The device or rod also provides mechanical loading of the sensor similar to that experienced in actual use. Care must be taken when using these devices to minimize resonances so that the characteristics of the sensor are not masked by these resonances.

3.4 These procedures allow comparison of responses only on the same test setup. No attempt should be made to compare responses on different test setups, whether in the same or separate laboratories.

4. Apparatus

4.1 The essential elements of the apparatus for these procedures are: *(1)* the acoustic emission sensor under test; *(2)* a block or rod; *(3)* a signal source; and *(4)* measuring and recording equipment.

4.1.1 Block diagrams of some of the possible experimental setups are shown in Fig. 1.

4.2 *Blocks* — The design of the block is not critical. However, the use of a "nonresonant" block is recommended for use with an ultrasonic transducer and is required when the transducer drive uses any form of coherent electrical signal.

4.2.1 *Conical "Nonresonant" Block* — The Beattie block, shown in Fig. 2, can be machined from a 10-cm (4-in.) diameter metal billet. The preferred materials are aluminum and low-alloy steel. After the bottom is faced and the taper cut, the block is clamped at a 10° angle and the top face is milled. The dimensions given will provide an approximate circle just over 2.5 cm (1 in.) in diameter for mounting the sensor. The acoustic excitation should be applied at the center of the bottom face. The conic geometry and lack of any parallel surfaces reduce the number of mechanical resonances that the block can support. A further reduction in possible resonances of the block can be achieved by roughly machining all surfaces except where the sensor and exciter are mounted and coating them with a layer of metal-filled epoxy.

4.2.2 *Gas-Jet Test Block* — Two gas-jet test blocks are shown in Fig. 3. The block shown in Fig. 3(a) is used for opposite surface comparisons, which produce primarily compressional waves. That shown in Fig. 3(b) is for same surface comparisons which produce primarily surface waves. The "nonresonant" block described in 4.2.1 can also be used with a gas jet in order to avoid exciting many resonant modes. The blocks in Fig. 3 have been used successfully but their design is not critical. However it is suggested that the relative positions of the sensor and the jet be retained.

4.2.3 *Acrylic Polymer Rod* — A polymethylmethacrylate rod is shown in Fig. 4. The sensor is mounted on the end of the rod and the acoustic excitation is applied by means of pencil lead break, a consistent distance from the sensor end of the rod. See Appendix X1 for additional details on this technique.

4.3 *Signal Sources* — Three signal sources are recommended: an electrically driven ultrasonic transducer, a gas jet, and an impulsive source produced by breaking a pencil lead.

4.3.1 *Ultrasonic Transducer* — Repeatable acoustic waves can be produced by an ultrasonic transducer permanently bonded to a test block. The transducer should be heavily damped to provide a broad frequency response and have a center frequency in the 2.25 to 5.0-MHz range. The diameter of the active element should be at least 1.25 cm (0.5 in.) to provide measurable signal strength at the position of the sensor under test. The ultrasonic transducer should be checked for adequate response in the 50 to 200-kHz region before permanent bonding to the test block.

4.3.1.1 *White Noise Generator* — An ultrasonic transducer driven by a white noise generator produces an acoustic wave that lacks coherent wave trains of many wave lengths at one frequency. This lack of coherent wave trains greatly reduces the number and strength of the mechanical resonances excited in a structure. Therefore, an ultrasonic transducer driven by a white-noise generator can be used with a resonant block having parallel sides. However, the use of a "nonresonant" block such as that described in 4.2.1 is strongly recommended. The generator should have a white-noise spectrum covering at least the frequency range from 10 kHz to 2 MHz and be capable of an output level of 1 V rms.

4.3.1.2 *Sweep Generator* — The ultrasonic transducer can be driven by a sweep generator in conjunction with a "nonresonant" block. Even with this block, some resonances will be produced that may partially mask the response of the sensor under test. The sweep generator should have a maximum frequency of at least 2 MHz and the sweep speed should be compatible with the XY recorder used. It is recommended that a sweep generator be used with an a-c voltmeter with a logarithmic output.

4.3.1.3 *Pulse Generator* — The ultrasonic transducer may be excited by a pulse generator. The pulse width should be either slightly less than one-half the period of the center frequency of the transducer (≤0.22 μs for a 2.25 MHz transducer) or longer than the damping time of the sensor, block, and transducer (typically >10 ms). The pulse repetition rate should be low (<100 pulses/s) so that each acoustic wave train is damped out before the next one is excited.

4.3.1.4 The pulse generator should be used with an oscilloscope and camera or, in single-pulse mode, with the counter in an acoustic emission system. Not enough energy is generated above 200 kHz for effective use with a spectrum analyzer.

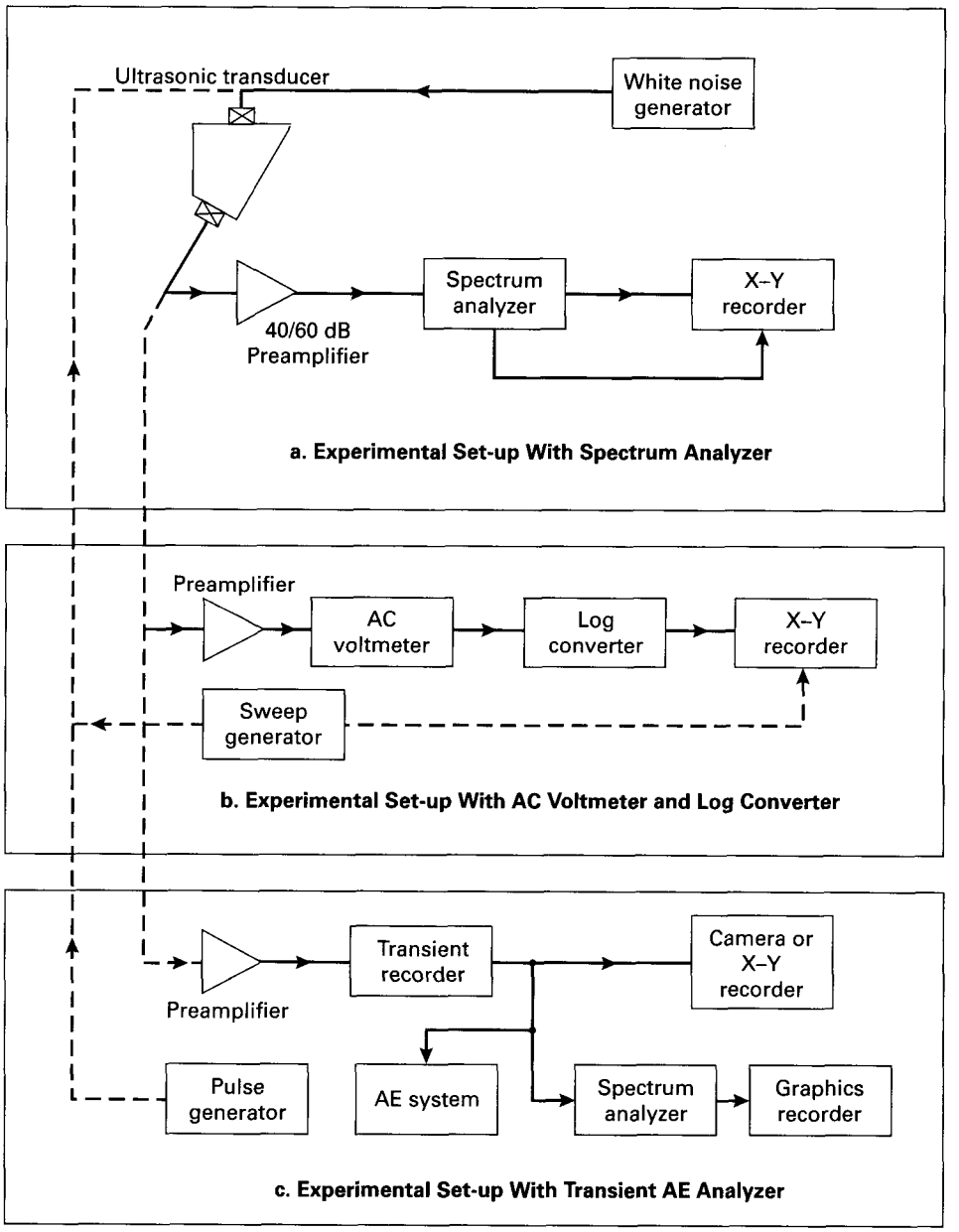
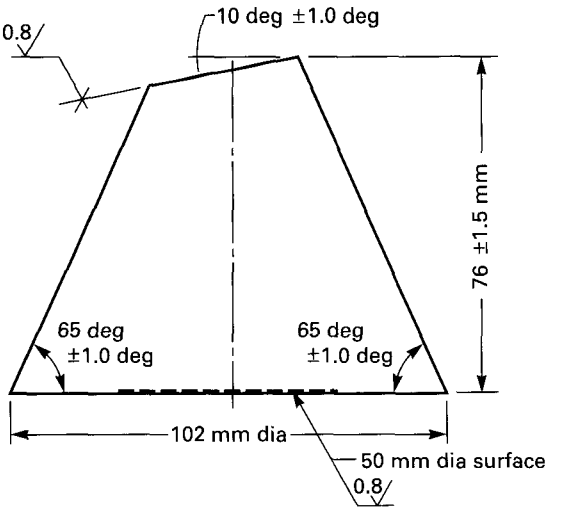


FIG. 1 BLOCK DIAGRAMS OF POSSIBLE EXPERIMENTAL SETUPS

4.3.2 *Gas Jet* — Suitable gases for this apparatus are extra dry air, helium, etc. A pressure between 150 and 200 kPa (20 to 30 psi) is recommended for helium or extra dry air. Once a pressure and a gas has been chosen, all further tests with the apparatus should use that gas and pressure. The gas jet should be permanently attached to the test block [see Fig. 3(a) and 3(b)].

4.3.3 *Pencil Lead Break* — A repeatable acoustic wave can be generated by carefully breaking a pencil lead against the test block or rod. When the lead breaks, there is a sudden release of the stress on the surface of the block where the lead is touching. This stress release generates an acoustic wave. The Hsu pencil source uses a mechanical pencil with a 0.3-mm diameter lead (0.5-mm lead is also acceptable but produces a larger signal). The Nielsen shoe, shown in Fig. 5 can aid in breaking the lead consistently. Care should be taken to always break the same length of the same type of lead (lengths between 2 and 3 mm are preferred). The lead should always be broken at the same spot on the block or rod with the same angle and orientation of the pencil. Spacing between the lead break and sensor should be at least 10



Finish: 3.2 and noted break edges 0.1 mm max.

FIG. 2 THE BEATTIE BLOCK

cm (4 in.). With distances shorter than that, it is harder to get consistent results. The most desirable permanent record of a pencil lead break is the wave form captured by a transient recorder or oscilloscope.

4.4 *Measuring and Recording Equipment* — The output of the sensor under test must be amplified before it can be measured. After the measurement, the results should be stored in a form that allows an easy comparison, either with another sensor or with the same sensor at a different time.

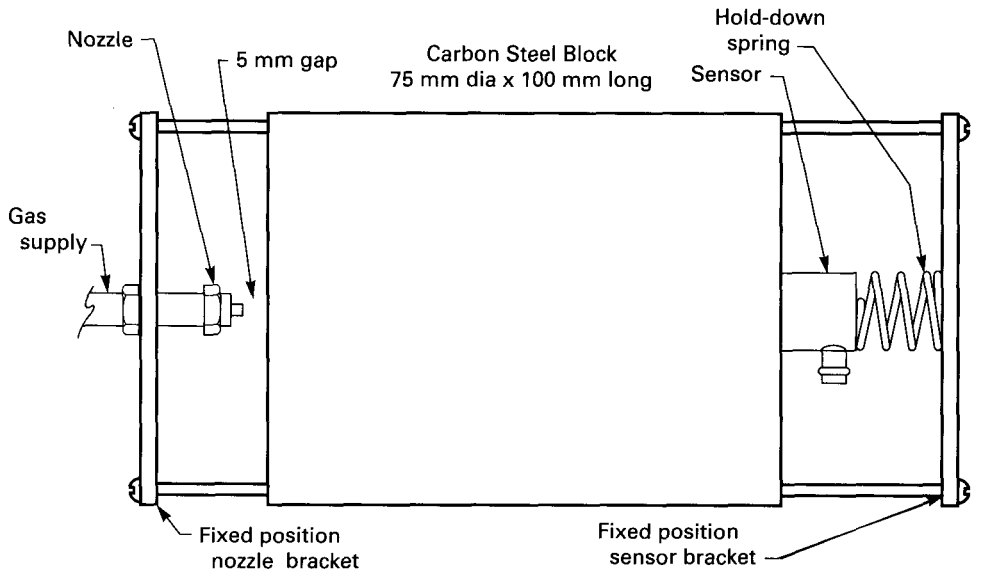
4.4.1 *Preamplifier* — The preamplifier, together with the sensor to preamp coaxial cable, provides an electrical load for the sensor, amplifies the output, and filters out unwanted frequencies. The electrical load on the sensor can distort the low-frequency response of a sensor with low inherent capacitance. To prevent this from occurring, it is recommended that short sensor cables (<2 m) be used and the resistive component of the preamplifier input impedance be 20 kΩ or greater. The preamplifier gain should be fixed. Either 40 to 60-dB gains are suitable for most sensors. The bandpass of the preamplifier should be at least 20 to 1200 kHz. It is recommended that one preamplifier be set aside to be used exclusively in the test setup. However, it may be appropriate at times to test a sensor with the preamplifier assigned to it in an experiment.

4.4.2 *Spectrum Analyzers* — A very useful instrument for testing sensor response is the spectrum analyzer. Spectrum analyzers can be used with acoustic signals generated by ultrasonic transducers that are driven by either white-noise generators or tracking-sweep generators, by gas-jet sources or by acoustic signals, produced by any source, that are captured on a transient recorder and replayed into the spectrum analyzer. A suitable spectrum analyzer should be capable of displaying a spectrum covering the frequency range from 20 kHz to 1.2 MHz. The amplitude should be displayed on a logarithmic scale covering a range from at least 50 dB in order to display the entire dynamic range of the sensor. The spectrum can be recorded photographically from an oscilloscope. However, the most useful output is an XY plot of the spectrum as shown in Fig. 6.

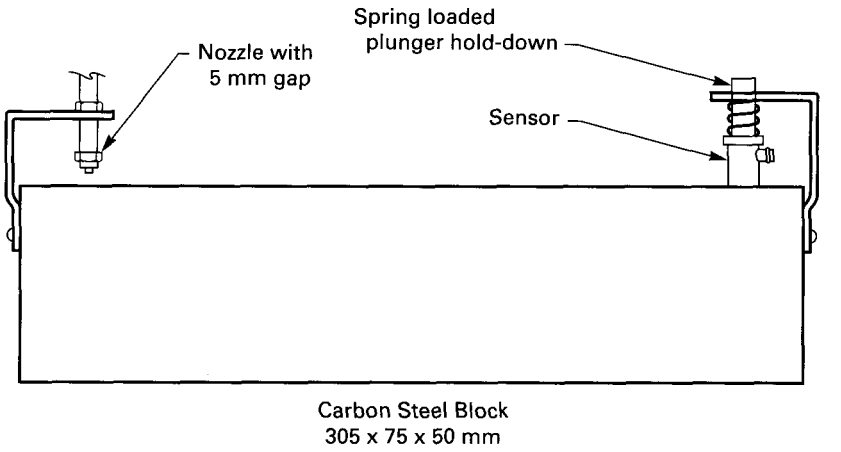
4.4.3 *Voltmeters* — An a-c voltmeter can be used to measure sensor outputs produced by signals generated by an ultrasonic transducer driven by a sweep generator. The response of the voltmeter should be flat over the frequency range from 10 kHz to 2 MHz. It is desirable that the voltmeter either have a logarithmic output or be capable of driving a logarithmic converter. The output of the voltmeter or converter is recorded on an XY recorder as a function of frequency.

4.4.3.1 The limited dynamic range of an rms voltmeter makes it less desirable than an a-c averaging voltmeter when used with a sweep generator. However, a rough estimate of a sensor performance can be obtained by using an rms or a-c voltmeter to measure the output of a sensor driven by a wide band source such as a white-noise generator or a gas jet.

4.4.4 *Acoustic Emission System* — A sensor can be characterized by using an acoustic emission system and



(a) Opposite Surface Comparison Test



(b) Same Surface Comparison Test

FIG. 3 GAS-JET TEST BLOCKS

an impulsive source such as a pencil lead break, an ultrasonic (or AE) transducer driven by a pulse generator, or the impulsive source that is built into many AE systems with automated pulsing capabilities. One or more of several significant AE signal features (such as amplitude, counts or energy) can be used to characterize the sensor response. The acoustic emission features from each signal pulse should be measured for multiple pulses (at least three). Data recorded should be the individual AE feature values (for repeatability determination) and average value of the readings (for sensitivity determination). In addition, the system gain, preamplifier gain, filtering, and any other significant settings of acoustic emission system should be recorded.

4.4.5 *Transient Recorders and Storage Oscilloscopes* — The waveform generated by a sensor in response to a single pulse or a pencil lead break can be measured and stored by a transient recorder, digital oscilloscope, or a waveform-based acoustic emission system. This waveform can be recorded on computer media, displayed on a computer screen or printed out on a printer

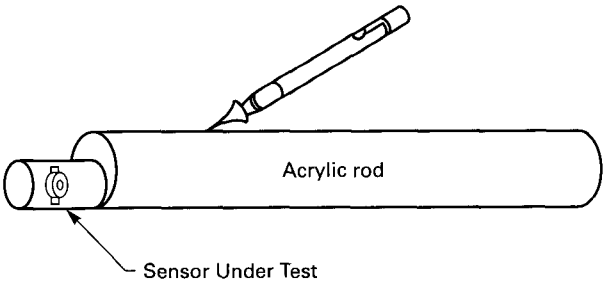


FIG. 4 ACRYLIC POLYMER ROD

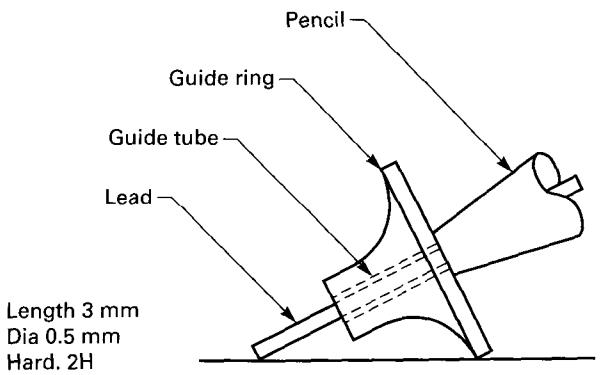
or X-Y recorder. Digitization rates should be at least 10 samples per highest frequency period in the waveform. Lower rates might result in distortion or loss of amplitude accuracy of the wave shape. When comparing waveforms, emphasis should be placed on the initial few cycles and on the large amplitude features. Small variations late in the waveform are often produced by slight changes in the coupling or position of the sensor under test. The waveform can also be converted into the frequency domain by means of a fast fourier transform (FFT) for amplitude versus frequency response analysis.

5. Procedure

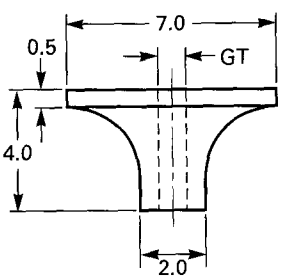
5.1 Place the sensors under test on the test block or rod in as near to identical positions as possible. Use identical forces to hold the sensor and block (or rod) together. A low-viscosity couplant is desirable to ensure reproducible and thin couplant thicknesses. For all setups, take several measurements before the final data is recorded to ensure reproducibility. During the initial measurements, display the preamplifier output on an oscilloscope to see that the signals are not being clipped by overdriving the preamplifier. Establish written procedures and follow them to ensure reproducibility over long periods of time.

6. Interpretation of Results

6.1 Short-term reproducibility of results, covering such actions as removing and remounting the sensor, should be better than 3 dB if the test is conducted under normal working conditions. Long-term reproducibility of the test system should be checked periodically by the use of a reference sensor that is not exposed to the risk of environmental damage. Variations of sensor response greater than 4 dB indicates damage or degradation, and the cause of the discrepancy should be further investigated. While there are no set criteria for acceptable limits on sensor degradation, a sensor whose sensitivity had fallen by more than 6 dB would generally be considered unfit for further service in acoustic emission measurements.



(a) Nielsen Shoe on Hsu Pencil Source



Diameter	GT (±0.05 mm)
0.3 mm	0.84 mm
0.5 mm	0.92 mm

Guide ring
Teflon
Dimensions given in mm
Tolerances ±0.1 mm
(unless otherwise noted)

(b) Nielsen Shoe

FIG. 5 GUIDE RING FOR IMPULSIVE SOURCE

Gas: extra dry air, 200 KPa
Nozzle: 0.25 mm dia diffused
Block: 305 mm x 75 mm x 50 mm carbon steel
Sensor and jet on same surface (50 x 305 mm), separation: 260 mm

AE instrumentation: Preamp: +40 dB gain
Amp: +21 dB gain
Filter: 100–400 kHz, bandpass

Spectrum analyzer: H.P. 8552B / 8553B
Center frequency: 250 kHz, bandwidth: 3 kHz
Scan/div: 50 kHz, Scan time: 2S/div
Input atten: 0 dB, log ref: 0 dB, 10 dB/division
Video filter: 10 Hz

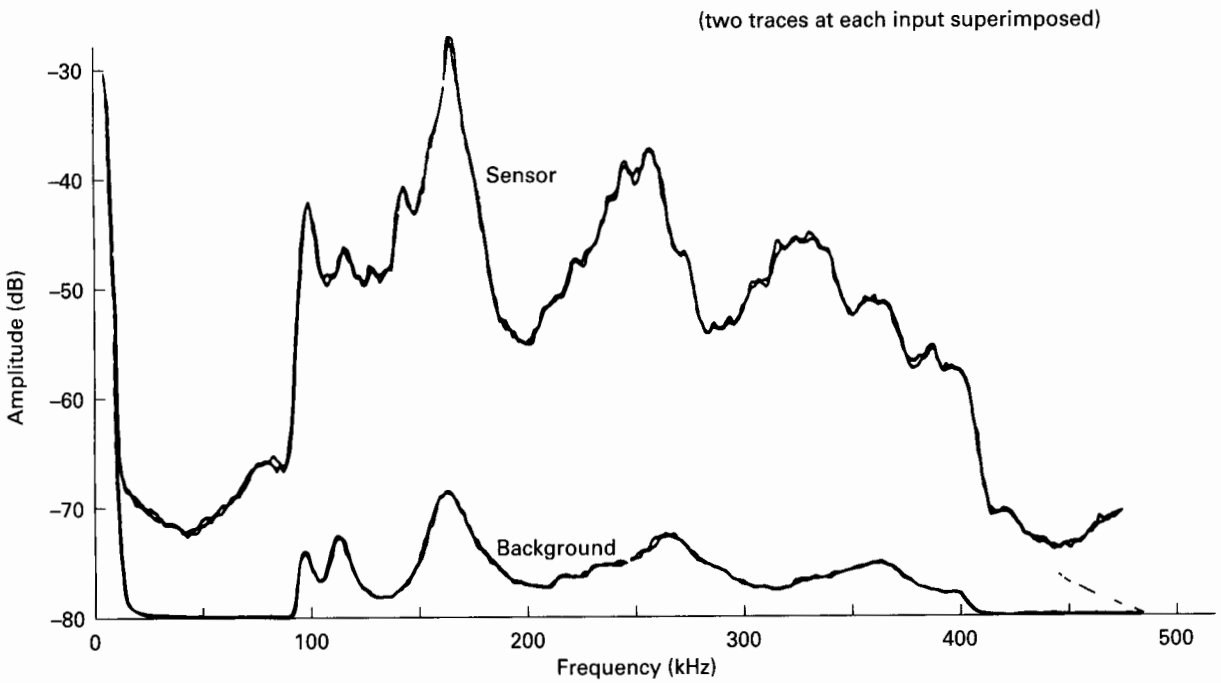


FIG. 6 EXAMPLE OF AN X-Y RECORDER PLOT FROM A SPECTRUM ANALYZER (150 kHz RESONANT SENSOR)

APPENDIX

(Nonmandatory Information)

X1. VERIFYING THE CONSISTENCY OF AE SENSOR RESPONSE USING AN ACRYLIC ROD

X1.1 *Scope*

X1.1.1 This procedure is recommended for routinely checking the sensitivity of acoustic emission (AE) sensors. It is intended to provide a reliable, precisely specified way of comparing a set of sensors and/or telling whether an individual sensor's sensitivity is degrading during its service life. This procedure is not a "calibration" nor does it give frequency response information. It is simply a way of verifying consistency of sensor peak amplitude response. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

X1.2 *Referenced Documents*

X1.2.1 *ASTM Standards:*

E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E 750 Practice for Characterizing Acoustic Emission Instrumentation

X1.3 Significance and Use

X1.3.1 Degradation in sensor performance can occur due to dropping, mechanical shock while mounted on the test structure, temperature cycles, etc. It is necessary and desirable to have a simple measurement procedure that will check the consistency of sensor response, over time or within a batch, while holding all other variables constant. While test blocks of many different kinds have been used for this purpose for many years, an acrylic polymer rod offers the best all-round combination of suitable acoustic properties, practical convenience, ease of procurement, and low cost.

X1.3.2 Since the acoustic properties of the acrylic rod are known to depend on temperature, this procedure requires that the rod, sensors, and couplant be stabilized at the same working temperature, prior to application of the practice.

X1.3.3 Properly applied and with proper record keeping, this procedure can be used in many ways. The user organization must determine the context for its use, the acceptance standards and the actions to be taken based on the lead break results. The following uses are suggested:

X1.3.3.1 To determine when a sensor is no longer suitable for use.

X1.3.3.2 To check sensors that have been exposed to high-risk conditions such as dropping, overheating, etc.

X1.3.3.3 To get an early warning of sensor degradation with time. This can lead to identifying conditions of use which are damaging sensors, and thus to better equipment care and lower replacement costs.

X1.3.3.4 To obtain matched sets of sensors, preamplifiers, and/or instrumentation channels for more uniform performance of the total system.

X1.3.3.5 To save time and money, by eliminating the installation of bad sensors.

X1.3.3.6 To verify sensors quickly but consistently in the field and to assist trouble-shooting when a channel does not pass a performance check.

X1.3.4 All the above uses are recommended for consideration. The purpose of this document is not to call out how these uses are to be implemented, but only to state how the test itself is to be performed so that the results obtained will be accurate and reliable.

X1.4 *Apparatus*

X1.4.1 The following apparatus are required in order to carry out this procedure:

X1.4.1.1 An acrylic polymer cylindrical rod (Fig. X1.1) should be used. The actual material of the acrylic polymer rod is polymethylmethacrylate. Some of the generic brand names of this material include, but are not limited to; Lucite PMMA, plexiglass, perspex, etc.

(1) Dimensions of the rod should be 78.74 cm (31 in.) long by 3.81 cm (1.5 in.) diameter, sensor end cut true and smooth with a surface finish of 0.4μm RMS (0.16 μin.).

(2) Other lengths of rod are acceptable, provided that there is sufficient distance to attenuate and prevent reflected signals from the non-sensor end of the rod reaching the sensor.

(3) A permanent reference mark (for example an "X") is placed on the rod at a distance of 10.16 cm (4 in.) from one end; this marks the spot where the lead is to

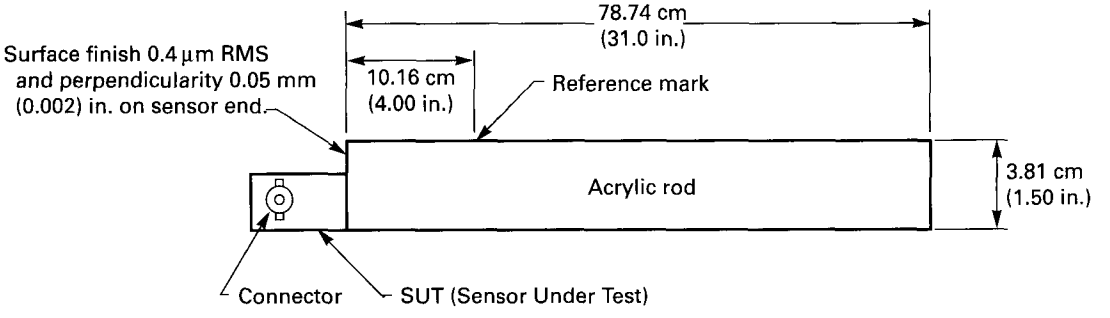


FIG. X1.1 ACRYLIC ROD DESCRIPTION

be broken. It is convenient to provide a very small spotface, for example, 0.5 mm (0.02 in.) in size at this reference mark point, to rest the tip of the pencil lead to avoid slippage during the lead break process.

NOTE X1.1 — The surface finish of the cylindrical rod section could produce reflections that affect AE response. The surface finish should be maintained in a clean, undamaged condition.

X1.4.2 A 0.3 or 0.5 mm Hsu-Nielsen pencil lead break source, with Nielsen shoe as described earlier in this guide, with 2H pencil lead.

X1.4.3 Sensor(s) to be tested.

X1.4.4 Acoustic emission equipment, with amplitude measurement capability, for recording sensor response. (Operating familiarity with the apparatus is assumed).

X1.4.5 Couplant, to be standardized and documented by the user of this guide.

X1.5 Procedure

X1.5.1 Assure that the acrylic rod, sensors and couplant have been allowed to stabilize to the working temperature of the examination environment.

X1.5.2 Place the prepared acrylic rod horizontally on a suitable hard, flat surface (such as a benchtop) with the 10.16 cm (4.0 in.) reference mark facing vertically up (12 o'clock). It may be secured with tape or other means no closer than 12 in. from the reference mark.

X1.5.3 Prepare and power-up the AE measurement system including preamplifier (if used) and connecting cables; allow warm up time as necessary; verify the system's performance. Verification may be accomplished on the rod using a reference sensor that is dedicated to this purpose and not exposed to the hazards of field use; or it may be accomplished by electronic procedures such as those described in Practice E 750.

X1.5.4 Mount the sensor to be tested on the flat end of the rod using the prescribed couplant. Wipe off any old couplant before mounting and do not let couplant from previous sensors accumulate under the rod. Mount the sensor in the 6 o'clock position so that it is resting on the same surface supporting the acrylic rod. This will prevent slipping of the sensor during sensor verification.

X1.5.5 Using the Hsu-Nielsen pencil lead source, break lead with the end of the 0.3 (or 0.5) mm lead in the center of the reference mark, with a lead extension of 2.5 mm ± 0.5 mm (0.1 in. ± 0.20 in.). Use the Nielsen shoe to obtain a consistent 30° angle between the lead and the surface. Hold the pencil pointing towards the sensor but with its axis approximately 22° (a quarter of a right angle) off from the axis of the rod, so that the lead flies off to one side and does not hit the sensor. Fingers may be rested on the rod on the side away from the sensor to steady the pencil, but there must be no finger contact or other materials in contact with the rod between pencil and sensor, except for the hard surfrace on which the acrylic rod is resting.

X1.5.6 Maintaining instrument settings, make three consistent lead breaks for each sensor, recording amplitude responses on a "Sensor Performance Verification Form", for example, similar to that shown in Fig. X1.2. Determine the average sensor amplitude response and proceed to the next sensor.

X1.5.7 Acceptance criteria (which should be assigned prior to conducting this practice by the testing organization) should be documented, for example as shown in Fig. X1.2, and applied to the sensor data recorded. Sensors failing the criteria should not be used during the examination, and should be returned for a more comprehensive analysis, repaired, or discarded.

X1.6 Precision and Bias

X1.6.1 Temperature variations are known to affect the acoustic absorption properties of the acrylic rod. However, since this is a comparative technique rather than an absolute one, this practice can be carried out with good results if all component parts used in the practice have been allowed to stabilize to the examination (environmental) temperature prior to application.

EXAMPLE OF SENSOR PERFORMANCE VERIFICATION FORM

DATE: _____ Start/End Times: _____ Job ID: _____

OPERATOR(S): _____ AMBIENT TEMPERATURE: _____

PENCIL TYPE: _____ LEAD TYPE: _____ SHOE: Y/N ____

SYSTEM MANUFACTURER MODEL: _____

SYSTEM SERIAL #: _____ CHANNEL #: _____

ROD ID: _____

SENSOR COUPLANT: _____ SENSOR CABLE LENGTH: _____

Sensor Model, SN#	Amplitudes (dBase)					Avg.	Sensor Model, SN#	Amplitudes (dBase)of					Avg.

AVG. AMPL. OF ALL SENSORS: ____dB ACCEPTANCE CRITERIA: +/–2 dB of Average Amplitude

COMMENTS/NOTES: _____

_____

_____

FIG. X1.2 SENSOR PERFORMANCE VERIFICATION FORM

X1.6.2 Rod-to-rod variations of several dB have been reported, but it is not certain whether these came truly from the rods or from some other source of variation.

X1.6.3 Person-to-person variations can be reduced to a range of 1 dB by proper technique and training.

X1.6.4 Variations in fracture performance within a lead and between leads are possible. With experience, occasional bad breaks can often be identified by the operator, even without reference to the results of the measurement.

X1.6.5 Bad breaks are relatively common as the pencil is about to run out of lead.

X1.6.6 Uniformity of material is a major quality goal of the lead manufacturer, but even so, runs of bad lead can occur due to manufacturing variations.

A06

STANDARD PRACTICE FOR LEAK DETECTION AND LOCATION USING SURFACE-MOUNTED ACOUSTIC EMISSION SENSORS

SE-1211

(Identical with ASTM Specification E 1211-02.)

1. Scope

1.1 This practice describes a passive method for detecting and locating the steady state source of gas and liquid leaking out of a pressurized system. The method employs surface-mounted acoustic emission sensors (for noncontact sensors, see Test Method E 1002), or sensors attached to the system via acoustic waveguides (for additional information, see Terminology E 1316), and may be used for continuous inservice monitoring and hydrotest monitoring of piping and pressure vessel systems. High sensitivities may be achieved, although the values obtainable depend on sensor spacing, background noise level, system pressure, and type of leak. This practice is not intended to provide a quantitative measure of leak rates.

1.2 The values stated in inch-pound units are to be regarded as the standard. SI units are provided for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E 750 Practice for Characterizing Acoustic Emission Instrumentation

E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E 1002 Test Method for Leaks Using Ultrasonics

E 1316 Terminology for Nondestructive Examinations

2.2 *Other Documents:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification

3. Summary of Practice

3.1 This practice requires the use of contact sensors, amplifier electronics, and equipment to measure their output signal levels. The sensors may be mounted before or during the test period and are normally left in place once mounted rather than being moved from point to point.

3.2 Detection of a steady-state leak is based on detection of the continuous, broadband signal generated by the leak flow. Signal detection is accomplished through measurement of some input signal level, such as its root-mean-square (RMS) amplitude.

3.3 The simplest leak test procedure involves *only* detection of leaks, treating each sensor channel individually. A more complex test requires processing the signal levels from two or more sensors together to allow computation of the approximate leak location, based on the principle that the leak signal amplitude decreases as a function of distance from the source.

4. Significance and Use

4.1 Leakage of gas or liquid from a pressurized system, whether through a crack, orifice, seal break, or other opening, may involve turbulent or cavitational flow, which generates acoustic energy in both the external atmosphere and the system pressure boundary. Acoustic energy transmitted through the pressure boundary can be detected at a distance by using a suitable acoustic emission sensor.

4.2 With proper selection of frequency passband, sensitivity to leak signals can be maximized by eliminating background noise. At low frequencies, generally below 100 kHz, it is possible for a leak to excite mechanical resonances within the structure that may enhance the acoustic signals used to detect leakage.

5. Basis of Application

5.1 *Personnel Qualification*

5.1.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, NAS-410, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

5.2 *Qualification of Nondestructive Agencies*

5.2.1 If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

5.3 *Timing of Examination*

5.3.1 The timing of examination shall be in accordance with 7.1.7 unless otherwise specified.

5.4 *Extent of Examination*

5.4.1 The extent of examination shall be in accordance with 7.1.4 and 10.1.1.1 unless otherwise specified.

5.5 *Reporting Criteria/Acceptance Criteria*

5.5.1 Reporting criteria for the examination results shall be in accordance with 10.2.2 and Section 11 unless otherwise specified. Since acceptance criteria are not specified in this standard, they shall be specified in the contractual agreement.

5.6 *Reexamination of Repaired/Reworked Items*

5.6.1 Reexamination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

6. Interferences

6.1 External or internal noise sources can affect the sensitivity of an acoustic emission leak detection system. Examples of interfering noise sources are:

6.1.1 Turbulent flow or cavitation of the internal fluid;

6.1.2 Noise from grinding or machining on the system;

6.1.3 Airborne acoustic noise, in the frequency range of the measuring system;

6.1.4 Metal impacts against, or loose parts frequently striking the pressure boundary; and

6.1.5 Electrical noise pick-up by the sensor channels.

6.2 Stability or constancy of background noise can also affect the maximum allowable sensitivity, since fluctuation in background noise determines the smallest change in level that can be detected.

6.3 The acoustic emission sensors must have stable characteristics over time and as a function of both the monitoring structure and the instrumentation system test parameters, such as temperature.

6.4 Improper sensor mounting, electronic signal conditioner noise, or improper amplifier gain levels can decrease sensitivity.

7. Basic Information

7.1 The following items must be considered in preparation and planning for monitoring:

7.1.1 Known existing leaks and their distance from the areas to be monitored should be noted so that their influence on the capabilities of the method can be evaluated.

7.1.2 Type of vessel, pipeline, or installation to be examined, together with assembly, or layout drawings, or both, giving sufficient detail to establish dimensions, changes of shape likely to affect flow characteristics, positions of welds, and the location of components such as valves or flanges, and attachments to the vessel or pipe such as pipe hangers where leaks are most likely to arise. Regions with restricted accessibility due to walls, the existence or location of cladding, insulation, or below-surface components must be specified.

7.1.3 When location of the peak is of primary interest, quantitative information regarding the leakage rates of interest, and whenever possible the type of leak, is necessary.

7.1.4 Extent of monitoring, for example, entire volume of pressure boundary, weld areas only, etc.

7.1.5 Material specifications and type of surface covering (for example, paint or other coating) to allow the acoustic propagation characteristics of the structure to be evaluated.

7.1.6 Proposed program of pressure application or process-pressure schedule, specifying the pressurization schedule together with a layout or sketch of the pressure-application system and specifying the type of fluid used during the test, for example, gas, water, or oil.

7.1.7 Time of monitoring, that is, the point(s) in the manufacturing process, or service life at which the system will be monitored, or both.

7.1.8 Frequency range to be used in the monitoring equipment.

7.1.9 Environmental conditions during examination that may affect instrumentation and interpretation of results; for example, temperature, moisture, radioactivity, vibration, pressure, and electromagnetic interference.

7.1.10 Limitations or restrictions on the sensor-mounting procedure, if applicable, including restrictions on couplant materials.

7.1.11 The location of sensors or waveguides and preparation for their installation to provide adequate coverage of the areas specified in 7.1.3. Where particular sections are to be examined with particular sensors, the coverage of the vessel or system by sensor subgroups shall be specified. The sensor locations must be given as soon as possible, to allow positioning difficulties to be identified.

7.1.12 The communications procedure between the acoustic emission staff and the control staff, the time intervals at which pressure readings are to be taken, and the procedure for giving warning of unexpected variations in the pressure system.

7.1.13 Requirements for permanent records, if applicable.

7.1.14 Content and format of test report, if required.

7.1.15 Acoustic Emission Examiner qualifications and certification, if required.

8. Apparatus

8.1 *Sensors* — The acoustic emission sensors are generally piezoelectric devices and should be mounted in accordance with Practice E 650 to ensure proper signal coupling. The frequency range of the sensors may be as high as 1 MHz, and either wideband or resonant sensors may be employed. The higher frequencies can be used to achieve greater discrimination against airborne or mechanical background noise.

8.2 *Amplifiers* — Amplifiers should have sufficient gain to allow the signal processing equipment to detect the level of acoustic background noise on the pressurized system. The sensor/amplifier bandwidth should be selected to minimize background noise.

8.3 *Signal Processor* — The signal processor measures the RMS level, the acoustic emission signal power, the average signal level, or any other similar parameters of the continuous signal. A leak location processor to compute the source location from signal levels and attenuation data may be included. Alarm set points may also be included as a processor function.

8.4 *Leak Signal Simulator:*

8.4.1 A device for simulating leaks should be included to evaluate the effectiveness of the monitor system. The following could be considered: a sensor on the pressure boundary driven from a random noise generator, a small water jet, or a gas jet.

8.4.2 When leak location processing is to be performed, leak simulation should be carried out initially over a sufficiently large number of diverse points to verify proper operation of the location algorithm.

9. Verification of Equipment Performance

9.1 Characterization consists of two stages. The first stage concerns periodic calibration and verification of the equipment under laboratory conditions. This procedure is beyond the scope of this practice (see Practice E 750) but the results must be made available to the system owners if requested. The second stage concerns in-situ verification to check the sensitivities of all channels and the satisfactory operation of the detection equipment. For every calibration operation, a written procedure shall be prepared.

9.2 In-situ sensitivity check of all sensors should be performed by placing a leak signal simulator (see Guide E 976) at a specified distance from each sensor and recording the resulting output level from the amplifier, as referred to the amplifier input terminal. Amplifier gains may also be adjusted as appropriate to correct for sensitivity variations.

9.3 Periodic sensitivity checks shall be made during long tests (days) or if any environmental changes occur. The relative sensitivity check is accomplished by driving various sensors or activating various leak simulation devices, such as water or gas jets, and measuring the

outputs of the receiving sensors. The ratio of the outputs of two receiving sensors for a given injection point should remain constant over time. Any change in the ratio indicates a deviation in performance. In this way, all sensors on a system may be compared to one or several reference signals and proper adjustments made (see Guide E 976).

9.4 When leak location calculations are to be performed, the acoustic attenuation between sensors should be characterized over the frequency band of interest, especially if the presence of discontinuities, such as pipe joints, may be suspected to affect the uniformity of attenuation. The measurements should then be factored into the source location algorithm.

10. Procedure

10.1 *Pre-Examination Requirements:*

10.1.1 Before beginning the acoustic emission monitoring, ensure that the following requirements are met:

10.1.1.1 Evaluate attenuation effects, that is, the change in signal amplitude with sound-propagation distance, so as to define the effective area covered by each individual sensor; and in the case of sensor subgroups, the maximum distance between sensing points.

10.1.1.2 Ensure that sensors are placed at the predetermined positions. If it is necessary to modify these positions during installation, record the new sensor locations. Record the method of attachment of the sensors and the couplant used.

10.1.1.3 Review the operating schedule to identify all potential sources of extraneous acoustic noise such as nozzle-plug movement, pump vibration, valve stroking, personnel movement, fluid flow, and turbulence. Such sources may require acoustic isolation or control so that they will not mask relevant leak emission within the vessel or structure being examined. Uncontrolled generation of acoustic interference by conditions such as rain, sleet, hail, sand, wind (for unprotected vessels), chipping, or grinding, shall be evaluated and its effect minimized by acoustic isolation insofar as is practical. A record shall be made of such sources.

10.2 *Acoustic Emission Monitoring:*

10.2.1 The noise level of each channel or each group shall be continuously or periodically recorded, as required. Pressure or other significant parameters, or both, will normally be recorded to allow correlation with the acoustic emission data response.

10.2.2 When an increase in noise level attributable to a leak has been detected, the examiner shall inform the system owner who will then look for the origin of the leak and its nature. If the leak is found to be outside the area of interest on the structure being monitored (extraneous leak), it must be stopped or reduced to a level necessary to ensure satisfactory monitoring. If extraneous leaks cannot be stopped, then the effect of such signals on the acoustic emission system sensitivity shall be noted. A report shall be prepared following the visual (or other) examination for leaks.

11. Report

11.1 Report the following information:

11.1.1 date of examination,

11.1.2 identity of examining personnel,

11.1.3 sensor characteristics and locations,

11.1.4 method of coupling sensors to the structure,

11.1.5 acoustic emission system and its characteristics,

11.1.6 operating conditions,

11.1.7 initial calibration results (laboratory),

11.1.8 in-situ calibration results and equipment verification,

11.1.9 results of measurements,

11.1.10 analysis and verification of results,

11.1.11 results of visual (or other) examination(s),

11.1.12 presentation of the numbers and locations of leaks detected,

11.1.13 analysis of background noise measurements,

11.1.14 estimate of quality of measurement and causes of any reduced sensitivity, and

11.1.15 conclusions and recommendations.

12. Keywords

12.1 acoustic emission; continuous monitoring; hydrotest; leak detection; nondestructive testing; piping systems; pressure vessels.

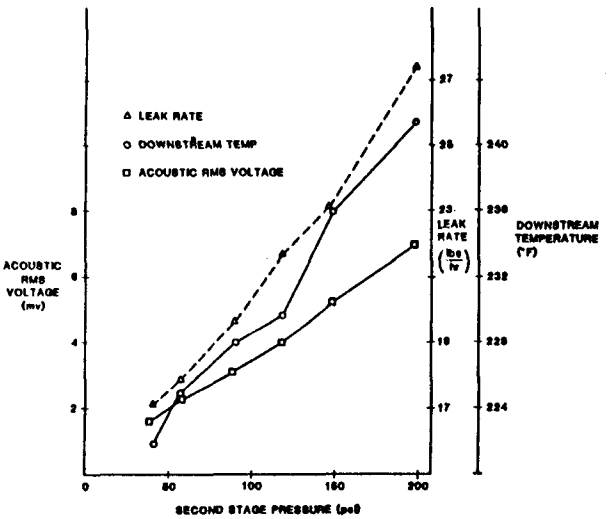
APPENDIX

(Nonmandatory Information)

X1. APPLICATIONS EXAMPLES

X1.1 The following examples were selected to illustrate application of acoustic emission leak detection, and are not intended to provide detailed descriptions of the application.

X1.1.1 *Acoustic Emission Leak Detection of a Safety/Relief Valve* — A safety/relief valve having a leaking pilot-disk seat was tested under laboratory conditions in order to determine the correlation of the leak noise with leak rate or second-stage pressure. The leak rate, downstream temperature, and the RMS voltage of the acoustic signal were plotted against the second-stage pressure in Fig. X1.1. The acoustic emission sensor was clamped onto the external housing of the pilot works. The signal was band-pass filtered in the range from 5 to 10 kHz. The downstream temperature was measured by a thermocouple in the vicinity of the "pilot valve discharge line." As the second stage pressure increased from 40 to 200 psi (280 to 1400 kPa), the leak rate increased 59%, the temperature increased 9%, and the acoustic emission RMS voltage increased 370%. Therefore, the sensitivity of the acoustic detection was excellent (see Fig. X1.1).



NOTE 1—0°F = 32°C.
NOTE 2—1 psi = 6.9 kPa.

FIG. X1.1 EXAMPLE OF ACOUSTIC EMISSION LEAK DETECTION IN A SAFETY/RELIEF VALVE OF A NUCLEAR POWER PLANT

X1.1.2 *Acoustic Emission Leak Detection from Seawater Ball Valves* — The U.S. Navy Acoustic Valve Leak Detector (AVLD) monitors leak-associated acoustic emission energy in the frequency range of 10 to 100 kHz. This frequency range was chosen because there is significant energy emitted by leaky valves, and energy in this range is rapidly attenuated with increasing distance from the source. Therefore, background noise can be electronically separated from the signal. Figure X1.2 shows the estimated leak rate versus acoustic emission level for a 4 in. ball valve.

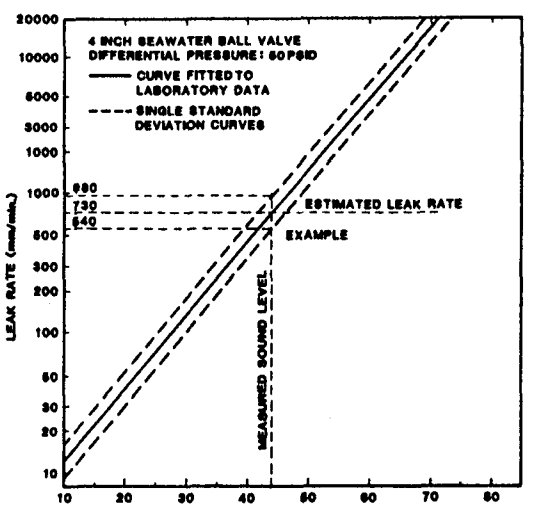


FIG. X1.2 ESTIMATING LEAK RATE FROM ACOUSTIC EMISSION LEVEL IN 4 in. SEAWATER BALL VALVES

X1.1.3 *Acoustic Emission Leak Detection of a Submerged Crude Oil Transfer Line* — A section of 12 in. diameter steel pipe terminating on an offshore drilling platform was inspected for confirmation of a suspected leak. During acceptance hydrotesting of the line, it was noted that pressure decayed at about 60 psi/h (410 kPa/h) starting at about 3200 psig (22 MPa). The suspected source of leakage was at the spool piece flanges. Signal level readings were taken on the 12 in. riser on the platform after the pressure on the pipe was elevated to 3200 psig (22 MPa). These signal readings were compared with readings taken on two adjacent pipes, and on the

nearest support leg for the structure (see Table X1.1). The additional readings were used to determine the amount of signal that was caused by sea motion and other structural interfering noise. The initial readings were taken with the platform in a shut-down condition and all construction workers onshore. The readings indicated about a 50% increase in signal level on the leaking pipe as compared to the other two risers and the support leg. This indicated leakage in close proximity to the detection point, in effect, verifying that leakage was in the connecting spool piece flanges. Following tightening by a diver of the identified leaking flange, the acoustic emission examiner determined that the leak had been stopped. No further indications of leakage were detected; either by mechanical means (pressure drop) or by acoustic emission.

TABLE X1.1
SIGNAL READINGS

Location	RMS Reading	Comment
6-in. pipe riser	0.200 at 60 dB gain	reference
10-in. pipe riser	0.210 at 60 dB gain	reference
12-in. pipe riser	0.300 at 60 dB gain	leaking pipe
Corner support leg	0.210 at 60 dB gain	reference

Location	RMS Reading	Comment
6-in. pipe riser	0.200 at 60 dB gain	reference
10-in. pipe riser	0.200 at 60 dB gain	reference
12-in. pipe riser	0.200 at 60 dB gain	leak noise is stopped
Corner support leg	0.210 at 60 dB gain	reference

A06

STANDARD TEST METHOD FOR EXAMINATION OF SEAMLESS, GAS-FILLED, PRESSURE VESSELS USING ACOUSTIC EMISSION

SE-1419

(Identical with ASTM Specification E 1419-02b.)

1. Scope

1.1 This test method provides guidelines for acoustic emission (AE) examinations of seamless pressure vessels (tubes) of the type used for distribution or storage of industrial gases.

1.2 This test method requires pressurization to a level greater than normal use. Pressurization medium may be gas or liquid.

1.3 This test method does not apply to vessels in cryogenic service.

1.4 The AE measurements are used to detect and locate emission sources. Other nondestructive test (NDT) methods must be used to evaluate the significance of AE sources. Procedures for other NDT techniques are beyond the scope of this test method. See Note 1.

NOTE 1 — Shear wave, angle beam ultrasonic inspection is commonly used to establish circumferential position and dimensions of flaws that produce AE.

1.5 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Agencies Performing Nondestructive Testing

E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E 1316 Terminology for Nondestructive Examinations

E 2223 Practice for Examination of Seamless, Gas-filled, Steel Pressure Vessels Using Angle Beam Ultrasonics

2.2 *ASNT Standards:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Code of Federal Regulations:*

Section 49, Code of Federal Regulations, Hazardous Materials Regulations of the Department of Transportation, Paragraphs 173.34, 173.301, 178.36, 178.37, and 178.45

2.5 *Compressed Gas Association Standard:*

Pamphlet C-5 Service Life, Seamless High Pressure Cylinders

3. Terminology

3.1 *Definitions* — See Terminology E 1316 for general terminology applicable to this test method.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *fracture critical flaw* — a flaw that is large enough to exhibit unstable growth at service conditions.

3.2.2 *marked service pressure* — pressure for which a vessel is rated. Normally this value is stamped on the vessel.

3.2.3 *normal fill pressure* — level to which a vessel is pressurized. This may be greater, or may be less, than *marked service pressure.*

4. Summary of Test Method

4.1 The AE sensors are mounted on a vessel, and emission is monitored while the vessel is pressurized above normal fill pressure.

4.2 Sensors are mounted at each end of the vessel and are connected to an acoustic emission signal processor. The signal processor uses measured times of arrival of emission bursts to determine linear location of emission sources. If measured emission exceeds a prescribed level (that is, specific locations produce enough events), then such locations receive secondary (for example, ultrasonic) examination.

4.3 Secondary examination establishes presence of flaws and measures flaw dimensions.

4.4 If flaw depth exceeds a prescribed limit (that is, a conservative limit that is based on construction material, wall thickness, fatigue crack growth estimates, and fracture critical flaw depth calculations), then the vessel must be removed from service.

5. Significance and Use

5.1 Because of safety considerations, regulatory agencies (for example, U.S. Department of Transportation) require periodic tests of vessels used in transportation of industrial gases (see Section 49, Code of Federal Regulations). The AE examination has become accepted as an alternative to the common hydrostatic proof examination. In the common hydrostatic examination, volumetric expansion of vessels is measured.

5.2 An AE examination should not be used for a period of one year after a common hydrostatic test. See Note 2.

NOTE 2 — The Kaiser effect relates to decreased emission that is expected during a second pressurization. Common hydrostatic examinations use a relatively high test pressure (167% of normal service pressure). (See Section 49, Code of Federal Regulations.) If an AE examination is performed too soon after such a pressurization, the AE results will be insensitive to a lower test pressure (that is, the lower pressure that is associated with an AE examination).

5.3 *Pressurization:*

5.3.1 General practice in the gas industry is to use low pressurization rates. This practice promotes safety and reduces equipment investment. The AE examinations should be performed with pressurization rates that allow vessel deformation to be in equilibrium with the applied load. Typical current practice is to use rates that approximate 500 psi/h (3.45 MPa/h).

5.3.2 Gas compressors heat the pressurizing medium. After pressurization, vessel pressure may decay as gas temperature equilibrates with ambient conditions.

5.3.3 Emission from flaws is caused by flaw growth and secondary sources (for example, crack surface contact and contained mill scale). Secondary sources can produce emission throughout vessel pressurization.

5.3.4 When pressure within a vessel is low, and gas is the pressurizing medium, flow velocities are relatively high. Flowing gas (turbulence) and impact by entrained particles can produce measurable emission. Considering this, acquisition of AE data may commence at some pressure greater than starting pressure (for example, $\frac{1}{3}$ of maximum test pressure).

5.3.5 *Maximum Test Pressure* — Serious flaws usually produce more acoustic emission (that is, more events, events with higher peak amplitude) from secondary sources than from flaw growth. When vessels are pressurized, flaws produce emission at pressures less than normal fill pressure. A maximum examination pressure that is 10% greater than normal fill pressure allows measurement of emission from secondary sources in flaws and from flaw growth.

5.3.6 *Pressurization Schedule* — Pressurization should proceed at rates that do not produce noise from the pressurizing medium and that allow vessel deformation to be in equilibrium with applied load. Pressure holds are not necessary; however, they may be useful for reasons other than measurement of AE.

5.4 Excess background noise may distort AE data or render them useless. Users must be aware of the following common sources of background noise: high gas-fill rate (measurable flow noise); mechanical contact with the vessel by objects; electromagnetic interference (EMI) and radio frequency interference (RFI) from nearby broadcasting facilities and from other sources; leaks at pipe or hose connections; and airborne sand particles, insects, or rain drops. This test method should not be used if background noise cannot be eliminated or controlled.

6. Basis of Application

6.1 *Personnel Qualification*

6.1.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally recognized NDT

personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Testing Agencies*

6.2.1 If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

6.3 *Time of Examination*

6.3.1 The timing of examination shall be in accordance with 5.2 unless otherwise specified.

6.4 *Extent of Examination*

6.4.1 The extent of examination includes the entire pressure vessel unless otherwise specified.

6.5 *Reporting Criteria/Acceptance Criteria*

6.5.1 Reporting criteria for the examination results shall be in accordance with Section 11 unless otherwise specified.

6.5.2 Since acceptance criteria (for example, reference radiographs) are not specified in this standard, they shall be specified in the contractual agreement.

6.6 *Reexamination of Repaired/Reworked Items*

6.6.1 Reexamination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

7. Apparatus

7.1 Essential features of the apparatus required for this test method are provided in Fig. 1. Full specifications are in Annex A1.

7.2 Couplant must be used to acoustically connect sensors to the vessel surface. Adhesives that have acceptable acoustic properties, and adhesives used in combination with traditional couplants, are acceptable.

7.3 Sensors may be held in place with magnets, adhesive tape, or other mechanical means.

7.4 The AE sensors are used to detect strain-induced stress waves produced by flaws. Sensors must be held in contact with the vessel wall to ensure adequate acoustic coupling.

7.5 A preamplifier may be enclosed in the sensor housing or in a separate enclosure. If a separate preamplifier is used, cable length, between sensor and preamp, must not exceed 6 ft (1.83 m).

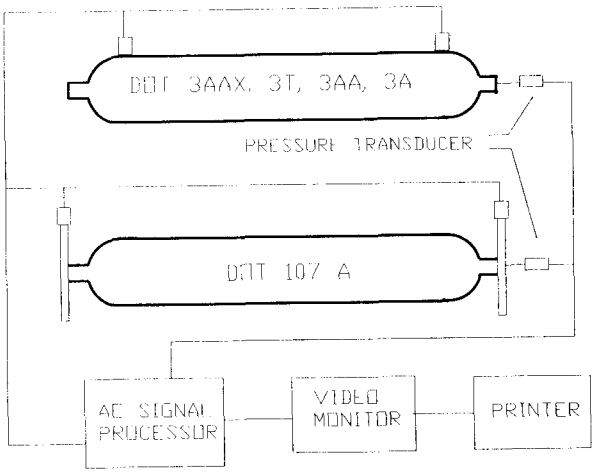


FIG. 1 ESSENTIAL FEATURES OF THE APPARATUS

7.6 Power/signal cable length (that is, cable between preamp and signal processor) shall not exceed 500 ft (152.4 m). See A1.5.

7.7 Signal processors are computerized instruments with independent channels that filter, measure, and convert analog information into digital form for display and permanent storage. A signal processor must have sufficient speed and capacity to independently process data from all sensors simultaneously. The signal processor should provide capability to filter data for replay. A printer should be used to provide hard copies of examination results.

7.7.1 A video monitor should display processed examination data in various formats. Display format may be selected by the equipment operator.

7.7.2 A data storage device, such as a floppy disk, may be used to provide data for replay or for archives.

7.7.3 Hard copy capability should be available from a graphics/line printer or equivalent device.

8. Safety Precautions

8.1 As in any pressure test of metal vessels, ambient temperature should not be below the ductile-brittle transition temperature of the pressure vessel construction material.

9. Calibration and Standardization

9.1 Annual calibration and verification of pressure transducer, AE sensors, preamplifiers (if applicable), signal processor (particularly the signal processor time reference), and AE electronic waveform generator should be

performed. Equipment should be adjusted so that it conforms to equipment manufacturer's specifications. Instruments used for calibrations must have current accuracy certification that is traceable to the National Institute for Standards and Technology (NIST).

9.2 Routine electronic evaluations must be performed any time there is concern about signal processor performance. An AE electronic waveform generator should be used in making evaluations. Each signal processor channel must respond with peak amplitude reading within ±2 dBV of the electronic waveform generator output.

9.3 A system performance verification must be conducted immediately before, and immediately after, each examination. A performance verification uses a mechanical device to induce stress waves into the vessel wall at a specified distance from each sensor. Induced stress waves stimulate a sensor in the same way as emission from a flaw. Performance verifications verify performance of the entire system (including couplant).

9.3.1 The preferred technique for conducting a performance verification is a pencil lead break (PLB). Lead should be broken on the vessel surface no less than 4 in. (10.16 cm) from the sensor. The 2H lead, 0.3-mm diameter, 3-mm long should be used (see Fig. 4 of Guide E 976).

9.3.2 *Auto Sensor Test (AST).* An electromechanical device such as a piezoelectric pulser (and sensor which contains this function) can be used in conjunction with pencil lead break (9.3.1) as a means to assure system performance. This device can be used to replace the PLB post examination, system performance verification (9.3).

10. Procedure

10.1 Visually examine accessible exterior surfaces of the vessel. Note observations in examination report.

10.2 Isolate vessel to prevent contact with other vessels, hardware, and so forth. When the vessel cannot be completely isolated, indicate, in the examination report, external sources which could have produced emission.

10.3 Connect fill hose and pressure transducer. Eliminate any leaks at connections.

10.4 Mount an AE sensor at each end of each tube. Use procedures specified in Guide E 650. Sensors must be at the same angular position and should be located at each end of the vessel so that the AE system can determine axial locations of sources in as much of the vessel as possible.

10.5 Adjust signal processor settings. See Appendix X1 for example.

10.6 Perform a system performance verification at each sensor (see 9.3). Verify that peak amplitude is greater than a specified value (see Table X1.2). Verify that the AE system displays a correct location (see Note 3) for the mechanical device that is used to produce stress waves (see 9.4 and Table X1.2). Prior to pressurization, verify that there is no background noise above the signal processor threshold setting.

NOTE 3 — If desired location accuracy cannot be attained with sensors at two axial locations, then more sensors should be added to reduce sensor spacing.

10.7 Begin pressurizing the vessel. The pressurization rate shall be low enough that flow noise is not recorded.

10.8 Monitor the examination by observing displays that show plots of AE events versus axial location. If unusual response (in the operator's judgment) is observed, interrupt pressurization and conduct an investigation.

10.9 Store all data on mass storage media. Stop the examination when the pressure reaches 110% of normal fill pressure or 110% of marked service pressure (whichever is greater). The pressure shall be monitored with an accuracy of ±2% of the maximum examination pressure.

10.9.1 *Examples:*

10.9.1.1 A tube trailer is normally filled to a gage pressure of 2640 psi (18.20 MPa). Pressurization shall stop at 2904 psi (20.02 MPa).

10.9.1.2 A gas cylinder is normally filled to a gage pressure of 613 psi (4.23 MPa). The marked service pressure is 2400 psi (16.55 MPa). Pressurization shall stop at 2640 psi (18.20 MPa).

10.10 Perform a system performance verification at each sensor (see 9.3). Verify that peak amplitude is greater than a specified value (see Table X1.2).

10.11 Reduce pressure in vessel to normal fill pressure by bleeding excess gas to a receiver, or vent the vessel.

10.12 Raw AE data should be filtered to eliminate emission from nonstructural sources, for example, electronic noise.

10.13 Replay examination data. Examine the location distribution plots (AE events versus axial location) for all vessels in the examination.

10.14 Based on data replay, determine whether secondary examination (ultrasonic examination) is required. (Ultrasonic examination should be performed in accordance with Practice E 2223.) Appendix X1 provides examples of such determinations.

11. Report

11.1 Prepare a written report from each examination. Report the following information:

11.1.1 Name of the owner of the vessel and the vehicle number (if appropriate).

11.1.2 Examination date and location.

11.1.3 Previous examination date and previous maximum test pressure. See Note 4.

NOTE 4 — If the operator is aware of situations where the vessel was subject to pressures that exceeded normal fill pressure, these should be described in the report.

11.1.4 Any U.S. Department of Transportation (DOT) specification that applies to the vessel.

11.1.5 Any DOT exemption numbers that apply to the vessel.

11.1.6 Normal fill pressure and marked service pressure.

11.1.7 Pressurization medium.

11.1.8 Pressure at which data acquisition commenced.

11.1.9 Maximum examination pressure.

11.1.10 Locations of AE sources that exceed acceptance criteria. Location shall include distance from end of vessel that bears the serial number (usually this is stamped in the vessel wall).

11.1.11 Signature of examiner.

11.1.12 Stacking chart that shows relative locations of vessels (if a multiple vessel array is tested).

11.1.13 Visual examination results.

11.1.14 AE examination results, including events versus location plots for each vessel and cumulative events versus pressure plot for each vessel.

12. Precision and Bias

12.1 Location accuracy is influenced by factors that affect elastic wave propagation, by sensor coupling, and by signal processor settings.

12.2 It is possible to measure AE and produce AE source locations that cannot be verified by other NDT methods. If such emissions are measured, and are produced by flaws, such flaws are small and are not of structural significance.

13. Keywords

13.1 acoustic emission; cylinders; flaws; gas pressure; seamless; steel

ANNEX

(Mandatory Information)

A1. INSTRUMENTATION SPECIFICATIONS

A1.1 Sensors

A1.1.1 The AE sensors shall have high sensitivity within the frequency band of 20 to 1200 kHz. Sensors may be broad band or resonant.

A1.1.2 Sensitivity shall be greater than −77 dBV (referred to 1 V/μbar, determined by face-to-face ultrasonic examination) within the frequency range of intended use.

A1.1.3 Sensitivity within the range of intended use shall not vary more than 3 dB over the intended range of temperatures in which sensors are used.

A1.1.4 Sensors shall be shielded against electromagnetic interference through proper design practice or differential (anticoincidence) element design, or both.

A1.1.5 Sensors shall be electrically isolated from conductive surfaces by means of a shoe (a wear plate).

A1.2 Signal Cable

A1.2.1 The sensor signal cable which connects sensor and preamplifier shall not sensor output more than 3 dB [6 ft (1.83 m) is a typical maximum length]. Integral preamplifier sensors meet this requirement. They have inherently short, internal, signal cables.

A1.2.2 Signal cable shall be shielded against electromagnetic interference. Standard coaxial cable is generally adequate.

A1.3 Couplant

A1.3.1 A couplant shall provide adequate ultrasonic coupling efficiency throughout the examination.

A1.3.2 The couplant must be temperature stable over the temperature range intended for use.

A1.3.3 Adhesives may be used if they satisfy ultrasonic coupling efficiency and temperature stability requirements.

A1.4 Preamplifier

A1.4.1 The preamplifier shall have noise level no greater than 7 μV rms (referred to a shorted input) within the bandpass range.

A1.4.2 The preamplifier gain shall vary no more than ±1 dB within the frequency band and temperature range of use.

A1.4.3 The preamplifier shall be shielded from electromagnetic interference.

A1.4.4 The preamplifiers of differential design shall have a minimum of 40-dB common mode rejection.

A1.4.5 The preamplifier shall include a bandpass filter with a minimum of 24-dB/octave signal attenuation above and below the 100 to 300-kHz frequency band.

A1.5 Power/Signal Cable

A1.5.1 The power/signal cables provide power to preamplifiers, and conduct amplified signals to the main processor. These shall be shielded against electromagnetic interference. Signal loss shall be less than 1 dB/100 ft (30.48 m) of cable length. Standard coaxial cable is generally adequate. Signal loss from a power/signal cable shall be no greater than 3 dB.

A1.6 Power Supply

A1.6.1 A stable, grounded, power supply that meets the signal processor manufacturer's specification shall be used.

A1.7 Signal Processor

A1.7.1 The electronic circuitry gain shall be stable within ±2 dB in the temperature range from 40 to 100°F (4.4 to 37.8°C).

A1.7.2 Threshold shall be accurate within ±2 dB.

A1.7.3 Measured AE parameters shall include: threshold crossing counts, peak amplitude, arrival time, rise time, and duration for each hit. Also, vessel internal pressure shall be measured.

A1.7.4 The counter circuit shall count threshold crossings within an accuracy of ±5% of true counts.

A1.7.5 Peak amplitude shall be accurate within ±2 dBV.

A1.7.6 Arrival time at each channel shall be accurate to within ±1.0 μs.

A1.7.7 Duration shall be accurate to within ±10 μs.

A1.7.8 Threshold shall be accurate to within ±1 dB.

A1.7.9 Arrival time shall be accurate to 0.5 μs.

A1.7.10 Rise time shall be accurate to ±10 μs.

A1.7.11 Parametric voltage readings from pressure transducers shall be accurate to within ±5% of the marked service pressure.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE INSTRUMENT SETTINGS AND REJECTION CRITERIA

X1.1 A database and rejection criteria are established for some DOT specified vessels. These have been described in the NDT Handbook. More recent criteria are described in this section. Some vessel types, typical dimensions, and service pressures are listed in Table X1.1.

X1.2 Criteria for determining the need for secondary examination were established while working with AE equipment with setup conditions listed in Table X1.2.

X1.3 Need for secondary examination is based on location distribution plots (that is, plots of AE events versus axial location) after AE data acquisition is completed.

X1.3.1 *Cylindrical Portion of Vessel* — The DOT 3AAX and 3T 3AA and 107A tubes are currently reexamined with this AE test method. For 3AAX and 3T and 3AA tubes, if five or more AE events occur within an 8-in. (20.3-cm) axial distance, on the cylindrical portion of a tube, then that part of the tube must be examined with a secondary NDT method (for example, ultrasonic examination). Any flaw that is detected must be precisely located, and flaw dimensions must be determined.

X1.3.2 *Ends of Vessel* — For DOT 3AAX and 3T and 3AA tubes, if five or more AE events are measured outboard of a sensor, each of these events is detected by both sensors, and the peak amplitude at the "first hit" sensor is 43 dBV or more, then the end of the tube at the "first hit sensor" (that is, the sensor with five or more first hits) must be examined. Any flaw that is detected must be precisely located, and flaw dimensions must be determined using secondary NDT method (for example, ultrasonic examination).

X1.3.3 The DOT 107A tubes are examined with sensors mounted on the end flanges. If five or more AE events occur within 8-in. (20.3-cm) axial distance on the cylindrical portion or end of the tube, then that part of the tube must be examined with a secondary NDT method (for example, ultrasonic examination). Any flaw that is detected must be precisely located, and flaw dimensions must be determined.

X1.4 *Rejection Criterion:*

X1.4.1 Vessels that contain flaws that are large enough to be "fracture critical flaws," or that contain flaws large enough to grow to fracture critical size before another reexamination is performed, shall be removed from service.

X1.4.2 "Fracture critical" flaw dimensions are based upon fracture mechanics analysis of a vessel using strength properties that correspond to materials of construction.

X1.4.3 Analyses of DOT 3AAX and 3T tubes are described by Blackburn and Rana. Fracture critical flaw depths were calculated, and fatigue crack growth (under worst case conditions) was estimated. Flaw depths that could grow to half the fracture critical size were judged too large. They should not remain in service. Based upon this conservative approach, DOT Specification 3AAX and 3T tubes with maximum flaw depths of 0.10 in. (2.54 mm), or more, should be permanently removed from service.

X1.4.3.1 The DOT 3AAX and 3T cylinders have been evaluated by Blackburn and Rana. The maximum allowable flaw depth was calculated to be 0.10 in. (2.54 mm).

X1.4.3.2 The DOT 3AA and 3A cylinders were evaluated by Blackburn. Maximum allowable depths were calculated and 0.06 in. (1.524 mm) was specified for both specifications.

X1.4.3.3 The DOT 107A cylinders have been evaluated by Toughiry. The maximum flaw depth was calculated to be 0.150 in. (3.81 mm).

TABLE X1.1
SPECIFIED CYLINDERS, TYPICAL DIMENSIONS, AND SERVICE PRESSURES

Specification	DOT 3AAX	DOT 3T	DOT 3A	DOT 3AA	DOT 107A
Outside diameter, in. (cm)	22 (55)	22 (56)	9.63 (25)	9.63 (25)	18 (46)
Nominal wall thickness, in. (cm)	0.54 (1.37)	0.42 (1.07)	0.31 (0.79)	0.25 (0.64)	0.75 or 0.86 (1.9 or 2.2)
Length, ft (m)	18 to 40 (0.5 to 12)		12 to 32 (4 to 10)		33 (10)
Typical service pressure, psi (MPa)	2400 (16.6)				2600 or 3300 (18 or 23)
Typical fill pressure, psi (MPa)	600 to 3000 (14.14 to 20.68)				2600 to 3300
Alternate retest method	hydrostatic test, at 1.67 times marked service pressure every five years with volumetric expansion measurement				

TABLE X1.2
ACOUSTIC EMISSION EQUIPMENT,
CHARACTERISTICS, AND SETUP CONDITIONS

Sensor sensitivity	−77 dBV ref. 1V/μbar, at ~150 kHz
Couplant	silicone grease
Preamplifier gain	40 dB (×100)
Preamplifier filter	100 to 300-kHz bandpass
Power/signal cable length	<500 ft (152.4 m)
Signal processor threshold	32 dBV (for example, 1 uV = 0 dBV at preamplifier input)
Signal processor filter	100 to 300-kHz bandpass
Dead time	10 ms
Background noise	<27 dBV (for example, 1 uV = 0 dBV at preamplifier input)
Sensitivity check	>70 dBV (PLB, 0.3 mm, 0.1 in., 4 in.)

ARTICLE 30
TERMINOLOGY FOR NONDESTRUCTIVE EXAMINATIONS STANDARD

A06

STANDARD TERMINOLOGY FOR NONDESTRUCTIVE EXAMINATIONS

SE-1316

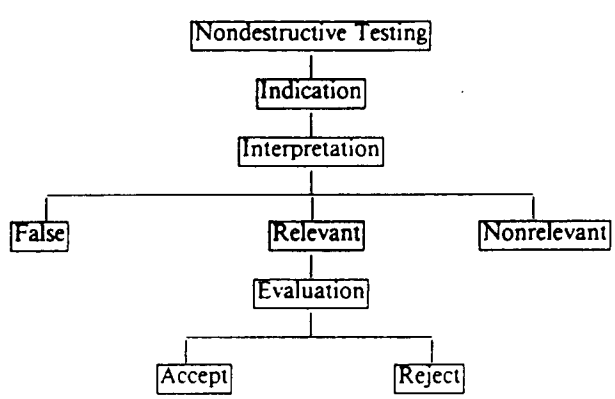
(Identical with ASTM E 1316-02a, except for editorial differences.)

1. Scope

1.1 This Standard defines the terminology used in the standards prepared by the E-7 Committee on Nondestructive Testing. These nondestructive testing (NDT) methods include: acoustic emission, electromagnetic testing, gamma- and X-radiology, leak testing, liquid penetrant examination, magnetic particle examination, neutron radiology and gaging, ultrasonic examination, and other technical methods.

1.2 Section 4 defines terms that are common to multiple NDT methods, whereas, the subsequent sections define terms pertaining to specific NDT methods. An alphabetical list of the terms defined in this Standard is given in Appendix Xl, which also identifies the section in which each term is defined.

1.3 As shown on the chart below, when nondestructive testing produces an indication, the indication is subject to interpretation as false, nonrelevant, or relevant. If it has been interpreted as relevant, the necessary subsequent evaluation will result in the decision to accept or reject the material. With the exception of *accept* and *reject*, which retain the meaning found in most dictionaries, all the words used in the chart are defined in Section 4.



2. Referenced Documents

2.1 *ASTM Standards:*

E 94 Guide for Radiograhic Examination

E 127 Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks

E 215 Practice for Standardizing Equipment for Electromagnetic Examination of Seamless Aluminum-Alloy Tube

E 494 Practice for Measuring Ultrasonic Velocity in Materials

E 566 Practice for Electromagnetic (Eddy-Current) Sorting of Ferrous Metals

E 664 Practice for Measurement of the Apparent Attenuation of Longitudinal Ultrasonic Waves by Immersion Method

E 750 Practice for Characterizing Acoustic Emission Instrumentation

E 804 Practice for Calibration of the Ultrasonic Test System by Extrapolation Between Flat-Bottom Hole Sizes

E 1033 Practice for Electromagnetic (Eddy-Current) Examination of Type F- Continuously Welded (CW) Ferromagnetic Pipe and Tubing Above the Curie Temperature

E 1067 Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels

E 1118 Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

E 1213 Test Method for Minimum Resolvable Temperature Difference for Thermal Imaging Systems

3. Significance and Use

3.1 The terms found in this proposed standard are intended to be used uniformly and consistently in all nondestructive testing standards. The purpose of this standard is to promote a clear understanding and interpretation of the NDT standards in which they are used.

4. Common NDT Terms

acceptable quality level — the maximum percent defective or the maximum number of units defective per hundred units that, for the purpose of sampling test, can be considered satisfactory as a process average

amorphous silicon (α-Si) X-ray detector, n — an amorphous silicon (α-Si) X-ray detector consists of a glass substrate with a matrix of photodiodes fabricated from amorphous silicon and switches arranged in rows and columns upon it; the photodiodes are activated by light photons emitted from a scintillator which is activated by X rays and is usually in close contact with the diode matrix

calibration, instrument, n — the comparison of an instrument with, or the adjustment of an instrument to, a known reference(s) often traceable to the National Institute of Standards and Technology (NIST). (See also *standardization, instrument.*)

defect, n — one or more flaws whose aggregate size, shape, orientation, location, or properties do not meet specified acceptance criteria and are rejectable

discontinuity, n — a lack of continuity or cohesion; an intentional or unintentional interruption in the physical structure or configuration of a material or component

evaluation — a review, following interpretation of the indications noted, to determine whether they meet specified acceptance criteria

examination, n — a procedure for determining a property (or properties) or other conditions or characteristics of a material or component by direct or indirect means

NOTE 1 — Examples include utilization of X rays or ultrasonic waves for the purpose of determining (directly or by calculation) flaw content, density, or (for ultrasound) modulus; or detection of flaws by induction of eddy currents, observing thermal behavior, AE response, or utilization of magnetic particles or liquid penetrants.

false indication, n — an NDT indication that is interpreted to be caused by a condition other than a discontinuity or imperfection

flaw, n — an imperfection or discontinuity that may be detectable by nondestructive testing and is not necessarily rejectable

flaw characterization, n — the process of quantifying the size, shape, orientation, location, growth, or other properties, of a flaw based on NDT response

imperfection, n — a depature of a quality characteristic from its intended condition

indication — the response or evidence from a nondestructive examination

DISCUSSION — An indication is determined by interpretation to be relevant, nonrelevant, or false.

inspection, n — a procedure for viewing or observing visual characteristics of a material or component in a careful, critical manner

NOTE 2— Examples include performance of a visual/optical inspection, observing the results of a magnetic particle or liquid penetrant examination, or carefully observing a surface condition prior to performing an ultrasonic or eddy-current examination. (From the same root word as "spectacle" or "spectator".)

interpretation — the determination of whether indications are relevant or nonrelevant

interpretation, n — the determination of whether indications are relevant, nonrelevant, or false.

Nondestructive Evaluation — see *Nondestructive Testing*

Nondestructive Examination — see *Nondestructive Testing*

Nondestructive Inspection — see *Nondestructive Testing*

Nondestructive Testing (NDT) — the development and application of technical methods to examine materials or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure, and evaluate flaws; to assess integrity, properties, and composition; and to measure geometrical characteristics

nonrelevant indication, n — an NDT indication that is caused by a condition or type of discontinuity that is not rejectable. False indications are nonrelevant.

relevant indication, n — an NDT indication that is caused by a condition or type of discontinuity that requires evaluation

standardization, instrument, n — the adjustment of an instrument using an appropriate reference standard, to obtain or establish a known and reproducible response. (This is usually done prior to an examination, but can be carried out anytime there is concern about the examination or instrument response.) (See also *calibration, instrument.*)

tset, n — a procedure for determining a property or characteristic of a material or a component by direct measurement

NOTE 3— Examples include mechanical tests to determine strength, hardness, or other property; determination of leakage (a leak test); or checking the performance (function) of a piece of equipment

5. Acoustic Emission (E 750, E 1067, and E 1118)

acoustic emission (AE) — the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material, or the transient waves so generated. Acoustic emission is the recommended term for general use. Other terms that have been used in AE literature include: *(1)* stress wave emission; *(2)* microseismic activity; and *(3)* emission or acoustic emission with other qualifying modifiers.

acoustic emission channel — see *channel, acoustic emission*

acoustic emission count (emission count) (N) — see *count, acoustic emission*

acoustic emission count rate — see *count rate, acoustic emission (emission rate or count rate) (N)*

acoustic emission event — see *event, acoustic emission*

acoustic emission event energy — see *energy, acoustic event*

acoustic emission sensor — see *sensor, acoustic emission*

acoustic emission signal amplitude — see *signal amplitude, acoustic emission*

acoustic emission signal (emission signal) — see *signal, acoustic emission*

acoustic emission signature (signature) — see *signature, acoustic emission*

acoustic emission transducer — see *sensor, acoustic emission*

acoustic emission waveguide — see *waveguide, acoustic emission*

acousto-ultrasonics (AU) — a nondestructive examination method that uses induced stress waves to detect and assess diffuse defect states, damage conditions, and variations of mechanical properties of a test structure. The AU method combines aspects of acoustic emission (AE) signal analysis with ultrasonic materials characterization techniques.

adaptive location — source location by iterative use of simulated sources in combination with computed location

AE activity, n — the presence of acoustic emission during a test

AE amplitude — see dB_{AE}

AE rms, n — the rectified, time averaged AE signal, measured on a linear scale and reported in volts

AE signal duration — the time between AE signal start and AE signal end

AE signal end — the recognized termination of an AE signal, usually defined as the last crossing of the threshold by that signal

AE signal generator — a device which can repeatedly induce a specified transient signal into an AE instrument

AE signal rise time — the time between AE signal start and the peak amplitude of that AE signal

AE signal start — the beginning of an AE signal as recognized by the system processor, usually defined by an amplitude excursion exceeding threshold

array, n — a group of two or more AE sensors positioned on a structure for the purposes of detecting and locating sources. The sources would normally be within the array.

arrival time interval (Δt_{ij}) — see *interval, arrival time*

attenuation, n — the decrease in AE amplitude per unit distance, normally expressed in dB per unit length

average signal level, n — the rectified, time averaged AE logarithmic signal, measured on the AE amplitude logarithmic scale and reported in dB_{ae} units (where 0 dB_{ae} refers to 1 μV at the preamplifier input)

burst emission — see *emission, burst*

channel, acoustic emission — an assembly of a sensor, preamplifier, or impedance matching transformer, filters, secondary amplifier, or other instrumentation as needed, connecting cables, and detector or processor

NOTE 4 — A channel for examining fiberglass reinforced plastic (FRP) may utilize more than one sensor with associated electronics. Channels may be processed independently or in predetermined groups having similar sensitivity and frequency characteristics.

continuous emission — see *emission, continuous*

count, acoustic emission (emission count) (N) — the number of times the acoustic emission signal exceeds a preset threshold during any selected portion of a test

count, event (N_e) — the number obtained by counting each discerned acoustic emission event once

count rate, acoustic emission (emission rate or count rate)(N) — the time rate at which emission counts occur

count ring-down — see *count, acoustic emission,* the preferred term

couplant — a material used at the structure-to-sensor interface to improve the transmission of acoustic energy across the interface during acoustic emission monitoring

cumulative (acoustic emission) amplitude distribution F(V) — see *distribution, amplitude, cumulative*

cumulative (acoustic emission) threshold crossing distribution $F_t(V)$ — see *distribution, threshold crossing, cumulative*

dB_{AE} — a logarithmic measure of acoustic emission signal amplitude, referenced to 1 μV.

$$\text{Signal peak amplitude } (dB_{AE}) = 20 \log_{10}(A_1/A_0)$$

where:

A_0 = 1 μV at the sensor output (before amplification)

A_1 = peak voltage of the measured acoustic emission signal

Acoustic Emission Reference Scale:

dB_{AE} Value	Voltage at Sensor Output
0	1 μV
20	10 μV
40	100 μV
60	1 mV
80	10 mV
100	100 mV

dead time — any interval during data acquisition when the instrument or system is unable to accept new data for any reason (E 750)

differential (acoustic emission) amplitude distribution f(V) — see *distribution, differential (acoustic emission) amplitude f(V)*

differential (acoustic emission) threshold crossing distribution $f_t(V)$ — see *distribution, differential (acoustic emission) threshold crossing*

distribution, amplitude, cumulative (acoustic emission) F(V) — the number of acoustic emission events with signals that exceed an arbitrary amplitude as a function of amplitude *V*

distribution, threshold crossing, cumulative (acoustic emission) $F_t(V)$ — the number of times the acoustic emission signal exceeds an arbitrary threshold as a function of the threshold voltage (V)

distribution, differential (acoustic emission) amplitude f(V) — the number of acoustic emission events with signal amplitudes between amplitudes of *V* and $V + \Delta V$ as a function of the amplitude *V*. *f(V)* is the absolute value of the derivative of the cumulative amplitude distribution *F(V)*.

distribution, differential (acoustic emission) threshold crossing $f_t(V)$ — the number of times the acoustic emission signal waveform has a peak between thresholds *V* and $V + \Delta V$ as a function of the threshold *V*. $f_t(V)$ is the absolute value of the derivative of the cumulative threshold crossing distribution $F_t(V)$.

distribution, logarithmic (acoustic emission) amplitude g(V) — the number of acoustic emission events with signal amplitudes between *V* and αV (where α is a constant multiplier) as a function of the amplitude. This is a variant of the differential amplitude distribution, appropriate for logarithmically windowed data.

dynamic range — the difference, in decibels, between the overload level and the minimum signal level (usually

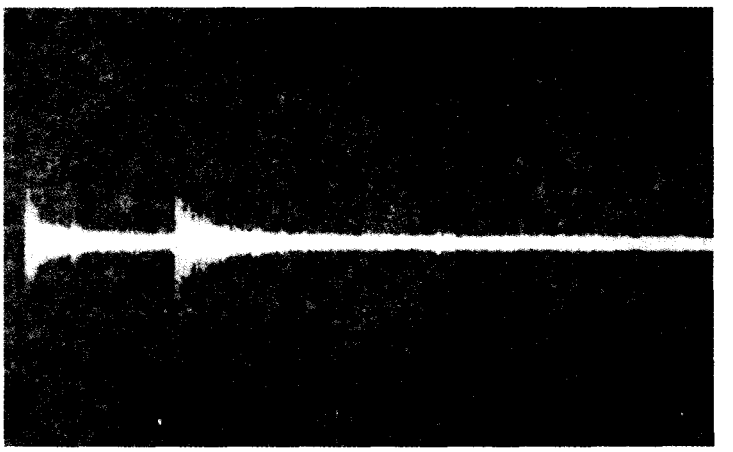


FIG. 1 BURST EMISSION ON A CONTINUOUS EMISSION BACKGROUND (SWEEP RATE — 5 ms/cm)

fixed by one or more of the noise levels, low-level distortion, interference, or resolution level) in a system or sensor

effective velocity, n — velocity calculated on the basis of arrival times and propagation distances determined by artificial AE generation; used for computed location

emission, burst — a qualitative description of the discrete signal related to an individual emission event occurring within the material

NOTE 5 — Use of the term burst emission is recommended only for describing the qualitative appearance of emission signals. Figure 1 shows an oscilloscope trace of burst emission signals on a background of continuous emission.

emission, continuous — a qualitative description of the sustained signal level produced by rapidly occurring acoustic emission from structural sources, leaks, or both

NOTE 6 — Use of the term *continuous emission* is recommended only for describing the qualitative appearance of emission signals. Figures 2 and 3 show oscilloscope traces of continuous emission signals at two different sweep rates.

energy, acoustic emission event — the total elastic energy released by an emission event

energy, acoustic emission signal — the energy contained in a detected acoustic emission burst signal, with units usually reported in joules and values which can be expressed in logarithmic form (dB, decibels)

evaluation threshold — a threshold value used for analysis of the examination data. Data may be recorded with a *system examination threshold* lower than the *evaluation threshold.* For analysis purposes, dependence of measured data on the *system examination threshold* must be taken into consideration.

event, acoustic emission (emission event) — a local material change giving rise to acoustic emission

event count (N_e) — see *count, event*

event count rate (N_e) — see *rate, event count*

examination area — that portion of a structure being monitored with acoustic emission

examination region — that portion of the test article evaluated using acoustic emission technology

Felicity effect — the presence of acoustic emission, detectable at a fixed predetermined sensitivity level at stress levels below those previously applied (E 1067)

Felicity effect — the presence of detectable acoustic emission at a fixed predetermined sensitivity level at stress levels below those previously applied

Felicity ratio — the ratio of the stress at which the Felicity effect occurs to the previously applied maximum stress (E 1067, E 1118)

NOTE 7 — The fixed sensitivity level will usually be the same as was used for the previous loading or test. (E 1118)

instrumentation dead time — see *dead time, instrumentation*

first hit location — a zone location method defined by which channel among a group of channels first detects the signal

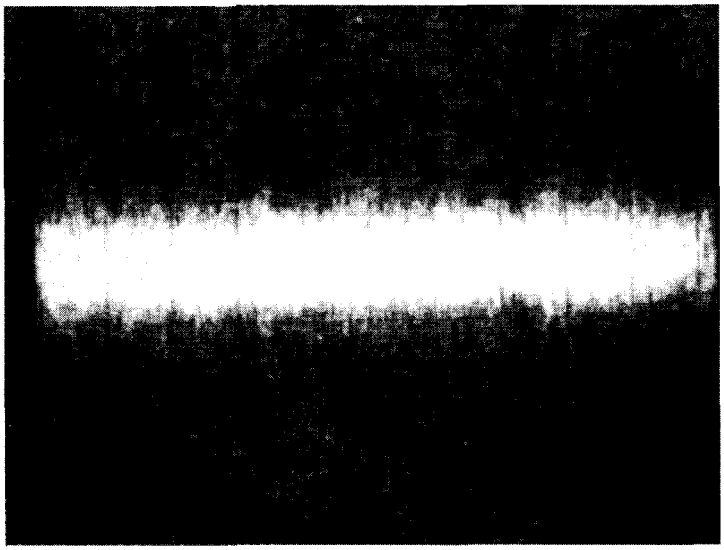


FIG. 2 CONTINUOUS EMISSION (SWEEP RATE — 5 ms/cm)

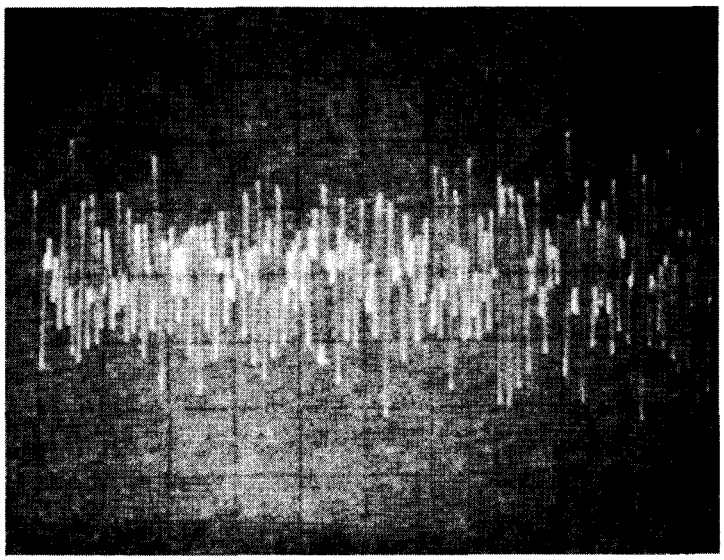


FIG. 3 CONTINUOUS EMISSION (SWEEP RATE — 0.1 ms/cm)

floating threshold — any threshold with amplitude established by a time average measure of the input signal (E 750)

hit — the detection and measurement of an AE signal on a channel

interval, arrival time (Δt_{ij}) — the time interval between the detected arrivals of an acoustic emission wave at the *ith* and *jth* sensors of a sensor array

Kaiser effect — the absence of detectable acoustic emission at a fixed sensitivity level, until previously applied stress levels are exceeded

location accuracy, n — a value determined by comparison of the actual position of an AE source (or simulated AE source) to the computed location

location, cluster, n — a location technique based upon a specified amount of AE activity located within a specified area, for example: 5 events within 12 linear in., or 12 sq. in.

location, computed, n — a source location method based on algorithmic analysis of the difference in arrival times among sensors

NOTE 8 — Several approaches to computed location are used, including linear location, planar location, three dimensional location, and adaptive location.

(a) linear location — one dimensional source location requiring two or more channels.

(b) planar location — two dimensional source location requiring three or more channels.

(c) 3D location — three dimensional source location requiring five or more channels.

(d) adaptive location — source location by iterative use of simulated sources in combination with computed location.

location, continuous AE signal, n — a method of location based on continuous AE signals, as opposed to hit or difference in arrival time location methods

NOTE 9 — This type of location is commonly used in leak location due to the presence of continuous emission. Some common types of continuous signal location methods include signal attentuation and correlation analysis methods.

(a) signal attenuation-based source location — a source location method that relies on the attenuation versus distance phenomenon of AE signals. By monitoring the AE signal magnitudes of the continuous signal at various points along the object, the source can be determined based on the highest magnitude or by interpolation or extrapolation of multiple readings.

(b) correlation-based source location — a source location method that compares the changing AE signal levels (usually waveform based amplitude analysis) at two or more points surrounding the source and determines the time displacement of these signals. The time displacement data can be used with conventional hit based location techniques to arrive at a solution for the source site.

location, source, n — any of several methods of evaluating AE data to determine the position on the structure from which the AE originated. Several approaches to source location are used, including zone location, computed location, and continuous location

location, zone, n — any of several techniques for determining the general region of an acoustic emission source (for example, total AE counts, energy, hits, and so forth)

NOTE 10 — Several approaches to zone location are used, including independent channel zone location, first hit zone location, and arrival sequence zone location.

(a) independent channel zone location, n — a zone location technique that compares the gross amount of activity from each channel.

(b) first-hit zone location, n — a zone location technique that compares only activity from the channel first detecting the AE event.

(c) arrival sequence zone location, n — a zone location technique that compares the order of arrival among sensors.

logarithmic (acoustic emission) amplitude distribution g(V) — see *distribution, logarithmic (acoustic emission) amplitude*

overload recovery time — an interval of nonlinear operation of an instrument caused by a signal with amplitude in excess of the instrument's linear operating range

performance check, AE system — see *verification, AE system*

pressure, design — pressure used in design to determine the required minimum thickness and minimum mechanical properties

processing capacity — the number of hits that can be processed at the processing speed before the system must interrupt data collection to clear buffers or otherwise prepare for accepting additional data

processing speed — the sustained rate (hits/s), as a function of the parameter set and number of active channels, at which AE signals can be continuously processed by a system without interruption for data transport

rate, event count (Ne) — the time rate of the event count

rearm delay time — see *time, rearm delay*

ring-down count — see *count, acoustic emission, the preferred term*

sensor, acoustic emission — a detection device, generally piezoelectric, that transforms the particle motion produced by an elastic wave into an electrical signal

signal, acoustic emission (emission signal) — an electrical signal obtained by detection of one or more acoustic emission events

signal amplitude, acoustic emission — the peak voltage of the largest excursion attained by the signal waveform from an emission event

signal overload level — that level above which operation ceases to be satisfactory as a result of signal distortion, overheating, or damage

signal overload point — the maximum input signal amplitude at which the ratio of output to input is observed to remain within a prescribed linear operating range

signature, acoustic emission (signature) — a characteristic set of reproducible attributes of acoustic emission signals associated with a specific test article as observed with a particular instrumentation system under specified test conditions

stimulation — the application of a stimulus such as force, pressure, heat, etc., to a test article to cause activation of acoustic emission sources

system examination threshold — the electronic instrument threshold (see *evaluation threshold*) at which data will be detected

transducers, acoustic emission — see *sensor, acoustic emission*

verification, AE system, (performance check, AE system) — the process of testing an AE system to assure conformance to a specified level of performance or measurement accuracy. (This is usually carried out prior to, during, and/or after an AE examination with the AE system connected to the examination object, using a simulated or artificial acoustic emission source.)

voltage threshold — a voltage level on an electronic comparator such that signals with amplitudes larger than this level will be recognized. The voltage threshold may be user adjustable, fixed, or automatic floating. (E 750)

waveguide, acoustic emission — a device that couples elastic energy from a structure or other test object to a remotely mounted sensor during AE monitoring. An example of an acoustic emission waveguide would be a solid wire or rod that is coupled at one end to a monitored structure, and to a sensor at the other end.

6. Electromagnetic Testing (E 215, E 243, E 566, E 1033)

absolute coil — a coil (or coils) that respond(s) to the total detected electric or magnetic properties, or both, of a part or section of the test part without comparison to another section of the part or to another part (E 566)

absolute measurements — in electromagnetic testing, measurements made without a direct reference using an absolute coil in contrast to differential and comparative measurements (see also *absolute coil*)

absolute readout — in electromagnetic testing, the signal output of an absolute coil (see also *absolute coil*)

absolute system — a system that uses a coil assembly and associated electronics to measure the total electromagnetic properties of a test part without direct comparison to another section of the part or to another part (see *absolute coil*) (E 566)

acceptance level — a test level above or below which test specimens are acceptable in contrast to rejection level

acceptance limits — test levels used in electromagnetic inspection that establish the group into which a material under test belongs

acceptance standard — in tubing inspection, a tube used to establish the acceptance level with artificial discontinuities as specified in the applicable product standard

acceptance standard — a tube with artificial discontinuities specified in the applicable product standard used to establish the acceptance level (E 215)

amplitude distortion — same as *harmonic distortion*

amplitude response — that property of a test system whereby the amplitude of the detected signal is measured without regard to phase (see also *harmonic analysis and phase analysis*)

annular coil clearance — the mean radial distance between adjacent coil assembly and test part surface in electromagnetic encircling coil examination

annular coils — see *encircling coils*

artificial discontinuity — reference discontinuities, such as holes, grooves, or notches that are introduced into a reference standard to provide accurately reproducible sensitivity levels for electromagnetic test equipment

band pass filter — a wave filter having a single transmission band, neither of the cut-off frequencies being zero or infinity

bobbin coil — see *ID coil*

bucking coils — same as *differential coils*

circumferential coils — see *encircling coils*

coil, absolute — see *absolute coil*

coil, reference — see *reference coil*

coil size — the dimension of a coil, for example, length or diameter

coil spacing — in electromagnetic testing, the axial distance between two encircling coils of a differential system

coil, test — in electromagnetic testing, the section of the probe or coil assembly that excites and/or detects the electromagnetic field in the material under test

comparative measurements — in electromagnetic testing, measurements made in which the unbalance in the system is measured using comparator coils in contrast to differential and absolute measurements. (See also *comparator coils.*)

comparative readout — in electromagnetic testing, the signal output of comparator coils. (See also *comparator coils.*)

comparative system — a system that uses coil assemblies and associated electronics to detect any electric or magnetic condition, or both, that is not common to the test specimen and the standard (see *comparator coils*) (E 566)

comparator coils — in electromagnetic testing, two or more coils electrically connected in series opposition but arranged so that there is no mutual induction (coupling) between them such that any electric or magnetic condition, or both, that is not common to the test specimen and the standard, will produce an unbalance in the system and thereby yield an indication

conductivity — the intrinsic property of a particular material to carry electric current; it is commonly expressed in percent IACS (International Annealed Copper Standard) or MS/m (Megasiemens/meter)

coupling — two electric circuits are said to be coupled to each other when they have an impedance in common so that a current in one causes a voltage in the other

cut-off level — same as *rejection level*

defect resolution — a property of a test system that enables the separation of indications due to defects in a test specimen that are located in close proximity to each other

depth of penetration — in electromagnetic testing, the depth at which the magnetic field strength or intensity of induced eddy currents has decreased to 37% of its surface value. The depth of penetration is an exponential function of the frequency of the signal and the conductivity and permeability of the material. Synonymous terms are *standard depth of penetration* and *skin depth.* (see also *skin effect*)

diamagnetic material — a material whose relative permeability is less than unity

NOTE 11 — The intrinsic induction Bi is oppositely directed to the applied magnetizing force *H*.

differential coils — two or more coils electrically connected in series opposition such that any electric or magnetic condition, or both, that is not common to the areas of a specimen being electromagnetically tested will produce an unbalance in the system and thereby yield an indication

differential measurements — in electromagnetic testing, measurements made in which the imbalance in the system is measured using differential coils in contrast to absolute and comparative measurements (see also *differential coils*)

differential readout — in electromagnetic testing, the signal output of differential coils (see also *differential coils*)

differential signal — in electromagnetic testing, an output signal that is proportional to the rate of change of the input signal

differential system — an electromagnetic testing system that uses coil assemblies and associated electronics to detect an electric or magnetic condition, or both, that is not common to the areas of the specimen being tested. (See also *differential coils.*)

eddy current — an electrical current caused to flow in a conductor by the time or space variation, or both, of an applied magnetic field

eddy current testing — a nondestructive testing method in which eddy current flow is induced in the test object. Changes in the flow caused by variations in the specimen are reflected into a nearby coil, coils, or Hall effect device for subsequent analysis by suitable instrumentation and techniques.

edge effect — in electromagnetic testing, the disturbance of the magnetic field and eddy currents due to the proximity of an abrupt change in specimen geometry (edge). This effect generally results in the masking of discontinuities within the affected region. (This effect is also termed the *end effect.*)

effective depth penetration (EDP) — in electromagnetic testing, for (a) thickness, the minimum depth beyond which a test system can no longer reliably detect a further increase in specimen thickness, or (b) defects, the limit for reliably detecting metallurgical or mechanical discontinuities by way of conventional continuous wave (CW) eddy current instrumentation and sensors. The EDP point is approximately three times the standard depth of penetration.

effective permeability — a hypothetical quantity that describes the magnetic permeability that is experienced under a given set of physical conditions such as a cylindrical test specimen in an encircling coil at a specific test frequency. This quantity may be different from the permeability of the particular metal being tested in that it takes into account such things as the geometry of the part, the relative position of the encircling coil, and characteristics of the magnetic field.

electrical center — the center established by the electromagnetic field distribution within a test coil. A constant intensity signal, irrespective of the circumferential position of a discontinuity, is indicative of electrical centering. The electrical center may be different from the physical center of the test coil.

electromagnetic testing — a nondestructive test method for materials, including magnetic materials, that uses electromagnetic energy having frequencies less than those of visible light to yield information regarding the quality of testing material

encircling coils — in electromagnetic testing, coil(s) or coil assembly that surround(s) the part to be tested. Coils of this type are also referred to as annular, circumferential, or feed-through coils.

end effect — see *edge effect*

end effect — the loss in sensitivity to discontinuities located near the extreme ends of the tube as the ends of the tube enter or leave the test coil (E 215)

feed-through coils — see *encircling coils*

ferromagnetic material — a material that, in general, exhibits the phenomena of magnetic hysteresis and saturation, and whose permeability is dependent on the magnetizing force

fill factor — for internal probe electromagnetic testing, the ratio of the effective cross-sectional area of the primary internal probe coil to the cross-sectional area of the tube interior

fill factor — for encircling coil electromagnetic testing, the ratio of the cross-sectional area of the test specimen to the effective cross-sectional core area of the primary encircling coil (outside diameter of coil form, not inside diameter which is adjacent to specimen)

filter — a network that passes electromagnetic wave energy over a described range of frequencies and attenuates energy at all other frequencies

frequency — the number of cycles per second of alternating electric current induced into the tubular product. For eddy-current testing described herein, the frequency is normally 1 to 125 kHz, inclusive. (E 215)

gate — same as *rejection level*

harmonic analysis — an analytical technique whereby the amplitude or phase, or both, of the frequency components of a complex periodic signal is determined

harmonic distortion — nonlinear distortion characterized by the appearance in the output of harmonics other than the fundamental component when the input wave is sinusoidal

IACS — the International Annealed Copper Standard; an international standard of electrical conductivity

ID coil — a coil or coil assembly used for electromagnetic testing by insertion into the test piece as in the case of an inside probe for tubing. Coils of this type are also referred to as inside coils, inserted coils, or bobbin coils.

impedance — the total opposition that a circuit presents to the flow of an alternating current, specifically the complex quotient of voltage divided by current

impedance analysis — in electromagnetic testing, an analytical method that consists of correlating changes in the amplitude, phase, or quadrature components, or all of these, of a complex test signal voltage to the electromagnetic conditions within the test specimen

impedance plane diagram — a graphical representation of the locus of points, indicating the variations in the impedance of a test coil as a function of basic test parameters

incremental permeability — the ratio of the change in magnetic induction to the corresponding change in magnetizing force when the mean induction differs from zero

indications — eddy-current signals caused by any change from uniformity of a tube. These changes from uniformity affect the electrical characteristic of the tube but may not be detrimental to the end use of the product (E 215)

initial permeability — the slope of the induction curve at zero magnetizing force as the test specimen is being removed from a demagnetizing condition (slope at origin of BH curve before hysteresis is observed)

inserted coil — see *ID coil*

inside coil — see *ID coil*

lift-off effect — the effect observed in an electromagnetic test system output due to a change in magnetic coupling between a test specimen and a probe coil whenever the distance between them is varied

magnetic history — magnetic condition of a ferromagnetic part under test based on previous exposures to magnetic fields (E 566)

magnetic leakage flux — the excursion of magnetic lines of force from the surface of a test specimen

magnetic saturation — that degree of magnetization where a further increase in magnetizing force produces no significant increase in magnetic flux density (permeability) in a specimen

modulation analysis — an analytical method used in electromagnetic testing that separates responses due to various factors influencing the total magnetic field by

separating and interpreting, individually, frequencies or frequency bands in the modulation envelope of the (carrier frequency) signal

noise — in electromagnetic inspection, any nonrelevant signal that tends to interfere with the normal reception or processing of a desired flaw signal. It should be noted that such noise signals may be generated by inhomogeneities in the inspected part that are not detrimental to the end use of the part.

nonferromagnetic material — a material that is not magnetizable and hence, essentially not affected by magnetic fields. This would include paramagnetic materials and diamagnetic materials.

normal permeability — the ratio of the induction (when cyclically made to change symmetrically about zero) to the corresponding change in magnetizing force

off-line testing — eddy current tests conducted on equipment that includes the test coil and means to propel individual tubes under test through the coil at appropriate speeds and conditions

on-line testing — eddy current tests conducted on equipment that includes the test coil and means to propel tubes under test through the coil at appropriate speeds and conditions as an integral part of a continuous tube manufacturing sequence

optimum frequency — in electromagnetic testing, that frequency which provides the largest signal-to-noise ratio obtainable for the detection of an individual material property. Each property of a given material may have its own optimum frequency.

paramagnetic material — a material that has a relative permeability slightly greater than unity and that is practically independent of the magnetizing force

permeability, a-c — a generic term used to express various dynamic relationships between magnetic induction, B, and magnetizing force, H, for magnetic material subjected to a cyclic excitation by alternating or pulsating current. The values of a-c permeability obtained for a given material depend fundamentally upon the excursion limits of dynamic excitation and induction, the method and conditions of measurement, and also upon such factors as resistivity, thickness of laminations, frequency of excitation, etc.

NOTE 12 — The numerical value for any permeability is meaningless unless the corresponding B or H excitation level is specified. For incremental permeabilities not only must the corresponding d-c B or H excitation level be specified, but also the dynamic range (ΔB or ΔH).

permeability, d-c — permeability is a general term used to express relationships between magnetic induction, B, and magnetizing force, H, under various conditions of magnetic excitation. These relationships are either *(1)* absolute permeability, which in general is the quotient of a change in magnetic induction divided by the corresponding change in magnetizing force, or *(2)* relative permeability, which is the ratio of the absolute permeability to the magnetic constant (γ_m).

NOTE 13 — The magnetic constant γ_m is a scalar quantity differing in value and uniquely determined by each electromagnetic system of units. In the unrationalized cgs system γ_m is 1 gauss/oersted and the mksa rationalized system $\gamma_m = 4\pi \times 10^{-7}$ H/m.

NOTE 14 — Relative permeability is a pure number which is the same in all unit systems. The value and dimension of absolute permeability depends on the system of units employed.

NOTE 15 — For any ferromagnetic material, permeability is a function of the degree of magnetization. However, initial permeability, μ_0 and maximum permeability, μ_m are unique values for a given specimen under specified conditions.

NOTE 16 — Except for initial permeability, μ_0, a numerical value for any of the d-c permeabilities is meaningless unless the corresponding B or H excitation level is specified.

NOTE 17 — For the incremental permeabilities $\mu\Delta$ and $\mu\Delta i$, a numerical value is meaningless unless both the corresponding values of mean excitation level (B or H) and the excursion range (ΔB or ΔH) are specified.

phase analysis — an analytical technique that discriminates between variables in a part undergoing electromagnetic testing part by the different phase angle changes that these conditions produce in the test signal. See also *phase detection.*

phase angle — the angular equivalent of the time displacement between corresponding points on two sine waves of the same frequency

phase detection — the derivation of a signal whose amplitude is a function of the phase angle between two alternating currents, one of which is used as a reference

phase-sensitive system — a system whose output signal is dependent on the phase relationship between the voltage returned from a pickup or sensing coil and a reference voltage

phase shift — a change in the phase relationship between two alternating quantities of the same frequency

probe coil — in electromagnetic testing, a small coil or coil assembly that is placed on or near the surface of test objects

probe coil clearance — the perpendicular distance between adjacent surfaces of the probe and test part; also lift-off

recovery time — the time required for a test system to return to its original state after it has received a signal

reference coil — a coil or probe, which may be used in conjunction with the appropriate material, to electrically balance a comparative system

reference standard — a tube, plate or part with artificial discontinuities used for establishing the test sensitivity setting and for periodically checking and adjusting sensitivity setting as required [see also *standard* (1)] (E 215)

rejection level — the value established for a test signal above or below which test specimens are rejectable, or otherwise distinguished from the remaining specimens

selectivity — the characteristic of a test system that is a measure of the extent to which an instrument is capable of differentiating between the desired signal and disturbances of other frequencies or phases

sensitivity control — the control in the instrument that adjusts the amplifier gain, and is one of the factors that determines the capacity to detect discontinuities (E 215)

signal gradient — same as *differential readout*

signal-to-noise ratio — the ratio of values to signal (response containing relevant information) to that of noise (response containing nonrelevant information)

skin depth — see *depth of penetration*

skin effect — the phenomenon wherein the depth of penetration of electric currents into a conductor decreases as the frequency of the current is increased. At very high frequencies, the current flow is restricted to an extremely thin outer layer of the conductor. (See also *depth of penetration.*)

speed effect — the phenomenon in electromagnetic testing of which the evidence is a change in the signal voltage resulting from a change in the relative motion between the specimen and a test coil assembly

standard — *(1)* a physical reference used as a basis for comparison or calibration; *(2)* a concept that has been established by authority, custom, or agreement to serve as a model or rule in the measurement of quality or the establishment of a practice or procedure.

standard depth of penetration — see *depth of penetration*

standard depth of penetration (SDP) — the depth at which the eddy current density is reduced to approximately 37% of the density at the surface. Eddy-current testing is most effective when the wall thickness does not exceed the SDP or in heavier tube walls when discontinuities of interest are within one SDP (E 215)

test coil — the section of the coil assembly that examines the material under test in a comparative system; the coil used to examine the material in an absolute or differential comparative system (E 566)

test frequency — in electromagnetic testing, the number of complete cycles per unit time of the alternating current applied to the primary test coil

test quality level — see *rejection level*

three way sort — an electromagnetic sort based on a signal response from the material under test above or below two levels established by three or more calibration standards

threshold level — the setting of an instrument that causes it to register only those changes in response greater or less than a specified magnitude

threshold setting — the setting of the instrument that causes it to register only those changes in eddy-current response greater than a specified magnitude (E 215)

NOTE 18 — Sensitivity and threshold settings usually are indicated by arbitrary numbers on the control panel of the testing instrument. These numerical settings differ among instruments of different types. It is, therefore, not proper to translate a numerical setting on one instrument to that of another type. Even among instruments of the same design and from the same manufacturer, sensitivity and threshold settings may vary slightly when detecting the same discontinuity. Therefore, undue emphasis on the numerical value of sensitivity and threshold settings is not justified. (E 215)

transducer — an electromagnetic device for converting electrical energy into magnetic or mechanical energy and vice versa (E 1033)

two-way sort — an electromagnetic sort based on a signal response from the material under test above or below a level established by two or more calibration standards

wobble — in electromagnetic testing, an effect that produces variations in coil spacing (operational lift-off) due to lateral motion of the test specimen in passing through an encircling coil

7. Gamma- and X-Radiology

absorbed dose — the amount of energy imparted by ionizing radiation per unit mass of irradiated matter.

Denoted by *rad*; 1 rad; = 0.01 j/kg. SI unit is *gray*; 1 gray = 1 j/kg.

absorbed dose rate — the absorbed dose per unit of time; rads/s. SI unit, grays/s.

absorption — the process whereby the incident particles or photons of radiation are reduced in number or energy as they pass through matter

accelerating potential — the difference in electric potential between the cathode and anode in an X-ray tube through which a charged particle is accelerated: usually expressed in units of kV or MV

activation — in neutron radiography, the process of causing a substance to become artificially radioactive by subjecting it to bombardment by neutrons or other particles

acute radiation syndrome — the immediate effects of a short term, whole body overexposure of a person to ionizing radiation. These effects include nausea and vomiting, malaise, increased temperature, and blood changes

alphanumeric — term pertaining to both numbers and alphabetical characters, typically used to designate a device capable of handling both types of characters

alpha particle — a positively charged particle emitted by certain radio-nuclides. It consists of two protons and two neutrons, and is identical to the nucleus of a helium atom

amorphous selenium (α-Se) radiation detector array — an array employing a biased amorphous selenium photo-conductor that directly converts incident radiation into electrical charge which can then be read to form a digital image

analog image — an image produced by a continuously variable physical process (for example, exposure of film)

analog to digital converter (a/d) — a device that changes an analog signal to a digital representation of the signal

anode — the positive electrode of a discharge tube. In an X-ray tube, the anode carries the target

anode current — the electrons passing from the cathode to the anode in an X-ray tube, minus the small loss incurred by the back scattered fraction

aperture — an opening in material, space, or time over which an element is considered to be active

area of interest — the specific portion of the object image on the radiograph that is to be evaluated

array processor — a special purpose logical processing device that performs extremely fast mathematical operations on digital arrays

artifact — spurious indication on a radiograph arising from, but not limited to, faulty manufacture, storage, handling, exposure, or processing

autoradiograph — the image of an object containing a radioelement obtained, on a recording medium, by means of its own radiation

back scattered radiation — radiation which is scattered more than 90 deg with respect to the incident beam, that is, backward in the general direction of the radiation source

betatron — an electron accelerator in which acceleration is provided by a special magnetic field constraining the electrons to a circular orbit. This type of equipment usually operates at energies between 10 and 31 MEV

blocking or masking — surrounding specimens or covering their sections with absorptive material

blooming — in radiologic real-time imaging, an undesirable condition exhibited by some image conversion devices and television pickup tubes brought about by exceeding the allowable input brightness for the device, causing the image to go into saturation, producing a fuzzy image of degraded spatial resolution and grey scale rendition

blow back — the enlargement of a minified radiograph to its original size by use of an optical direct reader

cassette — a light-tight container for holding radiographic recording media during exposure, for example, film, with or without intensifying or conversion screens

characteristic curve — the plot of density versus log of exposure or of relative exposure. (Also called the *D*-log *E* curve or the *H* and *D* curve.)

cine-radiography — the production of a series of radiographs that can be viewed rapidly in sequence, thus creating an illusion of continuity

collimator — a device of radiation absorbent material intended for defining the direction and angular divergence of the radiation beam

composite viewing — the viewing of two or more superimposed radiographs from a multiple film exposure

compton scatter radiation — the scattered X-ray or gamma ray, which results from the inelastic scattering of

an incident X-ray or gamma ray on an electron. Since the ejected electron has short range in most materials, it is not considered part of the scattered radiation

computed radiology (photo stimulated luminescence method) — a two-step radiological imaging process; first, a storage phosphor imaging plate is exposed to penetrating radiation; second, the luminescence from the plate's photostimulable luminescent phosphor is detected, digitized, and presented via hard copy or a CRT

constant potential — a method of electrically generating X-rays by placing a constant potential electrical source (voltage and current) across the X-ray tube anode and cathode; the ripple component of the constant potential electrical source is typically less than 2.0%

contrast sensitivity — a measure of the minimum percentage change in an object which produces a perceptible density/brightness change in the radiological image

contrast stretch — a function that operates on the greyscale values in an image to increase or decrease image contrast

definition, image definition — the sharpness of delineation of image details in a radiograph. Generally used qualitatively

densitometer — a device for measuring the optical density of radiograph film

density (film) — the quantitative measure of film blackening when light is transmitted or reflected.

$$D = \log (I_o/I) \text{ or } D = \log (I_o/R)$$

where

D = density
I_o = light intensity incident on the film
I = light intensity transmitted
R = light intensity reflected

density comparison strip — alternative term for *step-wedge comparison film.*

digital — the representation of data or physical quantities in the form of discrete codes, such as numerical characters, rather than a continuous stream

digital image — an image composed of discrete pixels, each of which is characterized by a digitally represented luminance level

digital image acquisition system — a system of electronic components which, by either directly detecting radiation or converting analog radiation detection information, creates an image of the spatial radiation intensity map comprised of an array of discrete digital intensity values (see *pixel*)

digital image enhancement — any operation used for the purpose of enhancing some aspect of the original image

digital image processing system — a system which uses algorithms to process digital image data

digitize (for radiology) — the act of converting an analog image or signal to a digital presentation

dynamic range (for radiology) — the span of signal intensity which defines the system's range of performance

equivalent I.Q.I. sensitivity — that thickness of I.Q.I. expressed as a percentage of the section thickness radiologically examined in which a 2T hole or 2% wire size equivalent would be visible under the same radiological conditions

equivalent penetrameter sensitivity — that thickness of penetrameter, expressed as a percentage of the section thickness radiographed, in which a 2T hole would be visible under the same radiographic conditions

erasable optical medium — an erasable and rewritable storage medium where the digital data is represented by the degree of reflectivity of the medium recording layer: the data can be altered

exposure, radiographic exposure — the subjection of a recording medium to radiation for the purpose of producing a latent image. Radiographic exposure is commonly expressed in terms of milliampere-seconds or millicurie-hours for a known source-to-film distance.

exposure table — a summary of values of radiographic exposures suitable for the different thicknesses of a specified material

film contrast — a qualitative expression of the slope or steepness of the characteristic curve of a film; that property of a photographic material which is related to the magnitude of the density difference resulting from a given exposure difference

film speed — a numerical value expressing the response of an image receptor to the energy of penetrating radiation under specified conditions

filter — uniform layer of material, usually of higher atomic number than the specimen, placed between the radiation source and the film for the purpose of preferentially absorbing the softer radiations

fluorescence — the emission of light by a substance as a result of the absorption of some other radiation of shorter wavelengths only as long as the stimulus producing it is maintained

fluorescent screen — alternative term for *intensifying screen (b)*

fluoroscopy — the visual observation on a fluorescent screen of the image of an object exposed to penetrating, ionizing radiation

focal spot — for x-ray generators, that area of the anode (target) of an x-ray tube which emits x-ray when bombarded with electrons

fog — a general term used to denote any increase in optical density of a processed photographic emulsion caused by anything other than direct action of the image forming radiation and due to one or more of the following:

(a) aging — deterioration, before or after exposure, or both, resulting from a recording medium that has been stored for too long a period of time, or other improper conditions;

(b) base — the minimum uniform density inherent in a processed emulsion without prior exposure

(c) chemical — resulting from unwanted reactions during chemical processing;

(d) dichroic — characterized by the production of colloidal silver within the developed sensitive layer;

(e) oxidation — caused by exposure to air during developing;

(f) exposure — arising from any unwanted exposure of an emulsion to ionizing radiation or light at any time between manufacture and final fixing;

(g) photographic — arising solely from the properties of an emulsion and the processing conditions, for example, the total effect of inherent fog and chemical fog;

(h) threshold — the minimum uniform density inherent in a processed emulsion without prior exposure.

fog density — a general term used to denote any increase in the optical density of a processed film caused by anything other than the direct action of the image-forming radiation

forward scattered radiation — radiation which is scattered less than 90 deg with respect to the incident beam, that is, forward in the general direction of the radiation source

gamma-radiography — a technique of producing radiographs using gamma-rays

gamma ray — electromagnetic penetrating radiation having its origin in the decay of a radioactive nucleus

geometric unsharpness — the penumbral shadow in a radiological image which is dependent upon:

(a) the radiation source dimensions;

(b) the source to object distance; and

(c) object to detector distance.

graininess — the visual impression of irregularity of silver deposit in a processed film

half-life — the time required for one half of a given number of radioactive atoms to undergo decay

half-value layer (HVL) — the thickness of an absorbing material required to reduce the intensity of a beam of incident radiation to one half of its original intensity

half-value thickness — the thickness of a specified substance which, when introduced into the path of a given beam of radiation, reduces its intensity to one half

image data file — a digital file containing radiological image and text information

image definition — see *definition*

image processing — a method whereby digital image data is transformed through a mathematical function

image quality indicator (IQI) — in industrial radiology, a device or combination of devices whose demonstrated image or images provide visual or quantitative data, or both, to determine radiologic quality and sensitivity. Also known as a penetrameter (disparaged).

NOTE 19 — It is not intended for use in judging size nor establishing acceptance limits of discontinuities.

indication, n — the response or evidence from a nondestructive examination that requires interpretation to determine relevance

intensifying screen — a material that converts a part of the radiographic energy into light or electrons and that, when in contact with a recording medium during exposure, improves the quality of the radiograph, or reduces the exposure time required to produce a radiograph, or both. Three kinds of screens in common use are:

(a) metal screen — a screen consisting of dense metal (usually lead) or of a dense metal compound (for example, lead oxide) that emits primary electrons when exposed to X- or gamma-rays;

(b) fluorescent screen — a screen consisting of a coating of phosphors which fluoresces when exposed to X or gamma radiation;

(c) fluorescent-metallic screen — a screen consisting of a metallic foil (usually lead) coated with a material

that fluoresces when exposed to X or gamma radiation. The coated surface is placed next to the film to provide fluorescence; the metal functions as a normal metal screen.

IQI sensitivity — in radiography, the minimum discernible image and the designated hole in the plaque-type, or the designated wire image in the wire type image quality indicator

keV (kilo electron volt) — a unit of energy equal to one thousand electron volts, used to express the energy of X-rays, gamma rays, electrons, and neutrons

kV (kilo volt) — a unit of electrical potential difference equal to one thousand volts, used to describe the accelerating potential of an X-ray tube

latent image — a condition produced and persisting in the image receptor by exposure to radiation and able to be converted into a visible image by processing

lead screen — see *intensifying screen (a)*

line pair test pattern — a pattern of one or more pairs of objects with high contrast lines of equal width and equal spacing. The pattern is used with an imaging device to measure spatial resolution.

linear accelerator — an electron generator in which the acceleration of the particles is connected with the propagation of a high-frequency field inside a linear or corrugated waveguide

line pairs per millimetre — a measure of the spatial resolution of an image conversion device. A line pair test pattern consisting of one or more pairs of equal width, high contrast lines, and spaces is utilized to determine the maximum density of lines and spaces that can be successfully imaged. The value is expressed in line pairs per millimetre.

location marker — a number or letter made of lead (Pb) or other highly radiation attenuative material that is placed on an object to provide traceability between a specific area on the image and the part

low-energy gamma radiation — gamma radiation having energy less than 200 keV

luminosity — a measure of emitted light intensity

mA (milli ampere) — a unit of current equal to 0.001 amperes, used to express the tube current of an X-ray tube

magnetic storage medium — a storage medium that uses magnetic properties (magnetic dipoles) to store digital data (for example, a moving drum, disk, or tape or a static core or film)

MeV (mega or million electron volts) — a unit of energy equal to one million electron volts, used to express the energy of X-rays, gamma rays, electrons, and neutrons

micro focus X-ray tube — an X-ray tube having an effective focal spot size not greater than 100 μm

milliamperes (mA) — the technical term is *tube current* and is defined as the current passing between the cathode and anode during the operation of an X-ray tube, measured in milliamperes (mA) and usually taken as a measure of X-ray intensity

minifocus X-ray tube — an X-ray tube having an effective focal spot size between 100 and 400 μm

MV (mega or million volt) — a unit of electrical potential difference equal to one million volts, used to describe the accelerating potential of an X-ray tube

net density — total density less fog and support (film base) density

neutron radiography (NRT) — a process of making an image of the internal details of an object by the selective attenuation of a neutron beam by the object

noise — the data present in a radiological measurement which is not directly correlated with the degree of radiation attentuation by the object being examined

nonerasable optical data — a nonerasable, nonrewriteable storage medium where the digital data is represented by the degree of reflectivity of the medium's recording layer. The data cannot be altered.

nonscreen-type film (direct-type film) — X-ray film designed for use with or without metal screens, but not intended for use with salt screens

nuclear activity — the number of disintegrations occurring in a given quantity of material per unit of time. *Curie* is the unit of measurement. One curie is equivalent to 3.7×10^{10} disintegrations per second.

object-film distance — the distance between the surface of the source side object and the plane of the recording medium

NOTE 20 — In the case where the recording medium is placed directly in contact with the object being examined, the distance is equal to the thickness of the object.

optical density — the degree of opacity of a translucent medium (darkening of film) expressed as follows:

$$OD = \log (I_o/I)$$

where:

OD = optical density
I_o = light intensity incident on the film
I = light intensity transmitted through the film

optical line pair test pattern — see *line pair test pattern*

pair production — the process whereby a gamma photon with energy greater than 1.02 MeV is converted directly into matter in the form of an electron-positron pair. Subsequent annihilation of the positron results in the production of two 0.511 MeV gamma photons.

pencil beam — a radiation beam which has little divergence, usually created by collimating an intense source of radiation

penetrameter — alternative term for *image quality indicator.*

penetrameter sensitivity — alternative term for *IQI sensitivity.*

phosphor — any substance that can be stimulated to emit light by incident radiation

photo fluorography — a photograph of the image formed on a fluorescent screen

photostimulable luminescence — the physical phenomenon of phosphors absorbing incident ionizing radiation, storing the energy in quasi-stable states and emitting luminescent radiation proportional to the absorbed energy when stimulated by radiation of a different wavelength

photostimulable luminescent phosphor —a phosphor capable of storing a latent radiological image, which, upon laser stimulation, will generate luminescence proportional to the radiation intensity

pixel — the smallest addressable element in an electronic image

pixel, display size — the dimensions of the smallest picture element comprising the displayed image, given in terms of the imaged object's dimensions being represented by the element

pixel size — the length and width of a pixel

primary radiation — radiation coming directly from the source

radiograph — a permanent, visible image on a recording medium produced by penetrating radiation passing through the material being tested

radiographic contrast — the difference in density between an image and its immediate surroundings on a radiograph

radiographic equivalence factor — that factor by which the thickness of a material must be multiplied in order to determine what thickness of a standard material (often steel) will have the same absorption

radiographic exposure — see *exposure*

radiographic inspection — the use of X-rays or nuclear radiation, or both, to detect discontinuities in material, and to present their images on a recording medium.

radiographic quality — a qualitative term used to describe the capability of a radiograph to show flaws in the area under examination

radiographic sensitivity — a general or qualitative term referring to the size of the smallest detail that can be seen on a radiograph, or the ease with which details can be seen

radiography — the art, act, or process of making radiographs

radiological examination — the use of penetrating ionizing radiation to display images for the detection of discontinuities or to help ensure integrity of the part

radiology — the science and application of X-rays, gamma-rays, neutrons, and other penetrating radiations

radioscopy — the electronic production of a radiological image that follows very closely the changes with time of the object being imaged

rare earth screens — see *intensifying screen*

real-time radioscopy — radioscopy that is capable of following the motion of the object without limitation of time

recording media — material capable of capturing or storing, or both, a radiological image in digital or analog form

recording medium — a film or detector that converts radiation into a visible image

representative quality indicator (RQI) — an actual part or similar part of comparable geometry and attentuation characteristics to that of the test part(s), that has known or measurable features, or both, representing the facets of nonconformance for which the test part is to be examined

scintillators and scintillating crystals — a detector that converts ionizing radiation to light

screen — alternative term for intensifying screen

secondary radiation — radiation emitted by any substance as the result of irradiation by the primary source

sensitivity — see *contrast sensitivity, equivalent IQI sensitivity, equivalent penetrameter sensitivity, IQI sensitivity, radiographic sensitivity*

shim — a material, typically placed under the IQI, which is radiologically similar to the object being imaged

signal — the data present in a radiological measurement which is directly correlated with the degree of radiation attenuation by the object being examined

source — a machine or radioactive material that emits penetrating radiation

source-film distance — the distance between the radiation producing area of the source and the film

step wedge — a device with discrete step thickness increments used to obtain an image with discrete density step values

step-wedge calibration film — a step-wedge comparison film the densities of which are traceable to a nationally recognized standardizing body

step-wedge comparison film — a strip of processed film carrying a stepwise array of increasing photographic density

step wedge comparison film — a radiograph with discrete density steps that have been verified by comparison with a calibrated step wedge film

storage phosphor imaging plate — a flexible or rigid reusable detector that stores a radiological image as a result of exposure to penetrating radiation

subject contrast — the ratio (or the logarithm of the ratio) of the radiation intensities transmitted by selected portions of the specimen

system induced artifacts — anomalies that are created by a system during the acquisition, display processing, or storage of a digital image

system noise — the noise present in a radiological measurement resulting from the individual elements of the radiological system

target — that part of the anode of an X-ray emitting tube hit by the electron beam

tenth-value-layer (TVL) — the thickness of the layer of a specified substance which, when introduced into the path of a given narrow beam of radiation reduces the intensity of this radiation by a factor of ten

tomography — any radiologic technique that provides an image of a selected plane in an object to the relative exclusion of structures that lie outside the plane of interest (see *tomogram* and *(CT) computed tomography)*

total image unsharpness — the blurring of test object features in a radiological image resulting from any cause(s)

translucent base media — materials with properties that allow radiological interpretation by transmitted or reflected light

transmission densitometer — an instrument that measures the intensity of the transmitted light through a radiographic film and provides a readout of the transmitted film density

transmitted film density — the density of radiographic film determined by measuring the transmitted light

tube current — the current, measured in milliamperes, passing between the cathode and anode during the operation of an X-ray tube

tube current — the transfer of electricity, created by the flow of electrons, from the filament to the anode target in an X-ray tube; usually expressed in unit of milliamperes

vacuum cassette — a flexible light-tight container that, when operated under a vacuum, holds film and screen in intimate contact during a radiographic exposure

8. Leak Testing

absolute manometer — a manometer whose calibration can be calculated from the measurable physical constants of the instrument and for which calibration is the same for all ideal gases

absolute pressure — pressure above the absolute zero corresponding to empty space, that is, local atmospheric pressure plus gage pressure

absorption — in leak testing, the binding or incorporation of gas in the interior of a solid (or liquid)

accumulation test — a leak test used to detect very small leaks in which gas contained in a component being tested will, if a leak is present, collect for a specified period of time in a closed evacuated chamber into which the component has been placed. At the end of the test period the chamber is opened to a leak detector which is sensitive to the gas.

TABLE 1
COMPOSITION AND PARTIAL PRESSURES OF THE ATMOSPHERE

Constituent	Volume %	Partial Pressure, kPa
At sea level (atmospheric pressure is 101 kPa)		
Oxygen	21	(0.21 × 101 =) 21
Nitrogen	78	(0.78 × 101 =) 79
Others	1	(0.01 × 101 =) 1
		Total atmospheric pressure, 101
At 3700-m altitude (atmosphere pressure is 64 kPa)		
Oxygen	21	(0.21 × 64 =) 13
Nitrogen	78	(0.78 × 64 =) 50
Others	1	(0.01 × 64 =) 1
		Total atmospheric pressure, 64

alkali ion diode — a sensor for halogen gases. See also *halogen leak detector (2).*

aperture leak — a leak of such geometric configuration that the length of the leakage path is much smaller than the shortest diameter of the path, so that the leak may be considered the equivalent of an opening in an infinitesimally thin wall

atmosphere (standard) — the pressure exerted by a mercury column 760 mm in height at 0°C under standard acceleration of gravity; equivalent to 101 325 Pa

atmospheric pressure — the pressure of the atmosphere at a specified place and time (see Table 1)

atomic mass unit (amu) — the unit of measure of the mass of a particle (atom, molecule, ion, etc.), defined as $^1/_{12}$ of the mass of carbon-12. The numerical value of the mass of a particle in terms of amu is identical with the older atomic weight.

audible leak indicator — an accessory to a leak detector which converts the output signal to an audible note whose frequency is a function of the leakage rate

back pressure — same as *forepressure*

back pressure test — same as *pressure-evacuation test*

background signal — in leak testing, the steady or fluctuating output signal of the leak detector caused by the presence of residual tracer gas or other substance to which the detecting element responds

backing pump — same as *fore pump*

backing space — the space between a backing pump (fore pump) and the associated diffusion pump (or other type of pump requiring a fore pump). See also *ballast.*

backing space technique — a method of testing for leaks in which the leak detector is connected to the backing space to take advantage of the compression of gas that occurs between the vacuum system and the backing pump, due to the action of the diffusion pump (or other type of pump of high speed relative to its backing pump)

bake-out — in leak testing, the degassing of a vacuum system by heating during the pumping process

ballast — in leak testing, a backing space large enough to maintain a low forepressure when the fore pump is temporarily stopped

Bayard-Alpert ionization gage — see *ionization vacuum gage*

bell jar — a container, open at one end (usually the bottom), which is used as a vacuum chamber or test vessel

bell jar testing — a test used for detecting leakage from an object completely or partially filled with a tracer gas and placed in a vacuum chamber or bell jar

bomb test — see *pressure-evacuation test*

bubble immersion test — a form of leak test of gas-containing enclosures in which a leak is indicated by the formation of a bubble at the site of a leak

clean-up — in leak testing, the time required for a leak testing system to reduce its signal output to 37% of the signal indicated at the time the tracer gas ceases to enter the leak system. Also called clean-up time.

clusec — an obsolete unit of flow rate equal to 10-2 lusecs

cold-cathode ionization gage — see *ionization vacuum gage*

concentration ratio — in leak testing, the ratio of the number of atoms (molecules) of a given constituent of a (gas) mixture to the total number of atoms (molecules) in the mixture. For ideal gases the concentration ratio has the same value as the volume fraction or the partial pressure of the constituent.

conductance — in leak testing, the ratio of the throughput (under steady state, conservative conditions) of a gas flowing through a conduit or an orifice to the difference in the partial pressures of the gas at the two ends of the conduit or on the two sides of the orifice, expressed in volume units per unit time, such as cubic metres per second

cracking — in leak testing, same as *dissociation*

differential leak detector — a leak detector employing two similar gage tubes in a bridge circuit with a trap which is selective for the tracer gas between the system and one of the tubes

differential Pirani gage — a leak detecting device employing two similar Pirani tubes as arms of a Wheatstone bridge

diffusion — in leak testing, the flow of the gas through a substance in which the gas actually migrates through the crystal lattice of the substance rather than through a geometrical leak (molecular diameters versus hole dimension)

discharge pressure — in leak testing, same as *fore-pressure*

discharge tube leak indicator — a glass tube attached to a system being leak tested, with the glass tube having electrodes attached to a source of high-frequency high voltage, such as a Tesla coil or induction coil, so that changes in the color of the electrical discharge can be observed when a suitable tracer gas (methane, carbon dioxide, alcohol) flows through the leak

dissociation — in leak testing, the breakdown of a substance into two or more constituents

NOTE 21 — Dissociation is sometimes referred to as cracking.

drift — in leak testing, the relatively slow change in the background output level of the leak detector due to the electronics rather than a change in the level of the tracer gas

dynamic leak test — a form of leak test in which some of the tracer gas entering through a leak is continually removed for sensing purposes

dynamic leakage measurement — leakage determined by measuring the tracer gas equilibrium partial pressure while the system is actively being pumped

dynamic sensitivity of leak detector — the minimum leak rate that the detector is capable of detecting while the enclosure under test is actively being evacuated continuously under specified conditions

equivalent nitrogen pressure — the calculated pressure that a gage or another device would indicate if the gas in the device were replaced by nitrogen at the same molecular density

exhaust pressure — in leak testing, same as *fore-pressure*

exhaust tubulation — same as *pump-out tubulation*

flooded system — a system which, while being tested, becomes so filled with tracer gas as to make impracticable further leak testing

flow — same as *flow rate*

flow rate — in leak testing, *(1)* the rate at which gas passes a given cross section of a system, determined by the product of the volume passing per unit time and its (partial) pressure at the cross section; *(2)* a product of the (partial) pressure difference of a gas at the ends of a conduit or across the face of an orifice, and the conductance of the gas for the conduit or orifice. Expressed in pressure-volume per unit time, such as pascal cubic metres per second.

fore-line — in leak testing, the line between a fore pump and the pump it backs

fore-line valve — in leak testing, a vacuum valve placed in the fore-line to permit isolation of the diffusion pump from its backing pump

forepressure — in leak testing, the total pressure on the outlet side of a pump measured near the outlet port. Sometimes called the back pressure, backing pressure, outlet pressure, exhaust pressure, or discharge pressure. In discussing the action of a vapor jet, the term forepressure may be used to designate the total pressure of the gas against which the jet impinges.

fore pump — in leak testing, the pump that produces the necessary fore vacuum for a pump which is incapable of discharging gases at atmospheric pressure. Sometimes called the backing pump.

gage pressure — difference between the absolute pressure and atmospheric pressure

gas — the state of matter in which the molecules are practically unrestricted by intermolecular forces so that the molecules are free to occupy all space within an enclosure. In vacuum technology, the word gas has been loosely applied to the uncondensed gas and vapor within a vacuum system.

halogen — any element of the family of the elements fluorine, chlorine, bromine, and iodine. Compounds do not fall under the strict definition of halogen. However, for the purpose of this standard, this word provides a convenient descriptive term for halogen-containing compounds. Of significance in halogen leak detection are those which have enough vapor pressure to be useful as tracer gases.

halogen leak detector — a leak detector that responds to halogen tracer gases. Also called halogen-sensitive leak

TABLE 2
DEGREES OF VACUUM

Degrees of Vacuum	Approximate Pressure Range
Low	100 kPa to 3 kPa
Medium	3 kPa to 0.1 Pa
High	0.1 Pa to 0.1 mPa
Very high	0.1 mPa to 0.1 μPa
Ultra high	0.1 μPa and less

detector or halide leak detector. *(1)* The copper-flame detector or halide torch consists of a bunsen burner with flame impinging on a copper plate or screen, and a hose with sampling probe to carry tracer gas to the air intake of the burner. *(2)* The alkali-ion diode halogen detector depends on the variation of positive ion emission from a heated platinum anode when halogen molecules enter the sensing element.

helium bombing — a pressure-evacuation test in which helium is used as the test gas

helium drift — *(1)* in leak testing with a probe, the drift from a leak or permeable gasket located at some distance from the end of the probe but which is detected by the probe and can mislead the operator into suspecting the area near the probe; *(2)* a gradual wandering of the output meter needle of the leak detector due to slowly changing helium concentrations (either due to a leak or outgassing) in the detector tube. Expressed in scale divisions per unit time.

helium leak detector — a leak detector using helium as the tracer gas

hermetically tight seal — a seal which does not exhibit leakage when dynamically tested with commercially built leak detectors that are sensitive to a gas on the pressure side opposite to the side on which the leak detector is located, or which does not exhibit leakage with any form of liquid test

high vacuum — see Table 2

holding pump — a fore pump used to hold a vapor pump at operating conditions while a roughing pump reduces the system pressure to a point at which the valve between the vapor pump and the system can be opened without stopping the flow of vapor from the nozzles

hood test — an overall test in which an object under vacuum test is enclosed by a hood which is filled with tracer gas so as to subject all parts of the test object to examination at one time. A form of dynamic leak test in which the entire enclosure or a large portion of its external surface is exposed to the tracer gas while the interior is connected to a leak detector with the objective of determining the existence of leakage.

hot-cathode ionization gage — see *ionization vacuum gage*

hot-filament ionization gage — see*ionization vacuum gage*

hydraulic pressure test — same as *hydrostatic test*

hydrostatic test — in leak testing, a pressure test in which the component being tested is filled completely with water or another liquid. Pressure, if required, is then applied to the liquid for the required time and the outside of the component is examined visually for leaks.

ideal gas — a gas that obeys Boyle's law and has zero heat of free expansion (or also obeys Charles' law). Also known as a perfect gas.

in-leakage rate — the combined leakage rate from all existing leaks in a specified evacuated vessel in pressure volume units per unit of time

inlet — the opening, flange, connection, or coupling on a leak detector or leak testing system through which the tracer gas may enter due to a leak in an object under test

inlet flange — see *inlet*

inlet port — see *inlet*

inside-out testing — see *bell jar testing*

ion pump — an electrical device for pumping gas comprising a means for ionizing the gas and a system of electrodes at suitable potentials, and in some cases also a magnetic field, which causes the ions formed to move towards a surface on which they are absorbed or buried

ion source — in leak testing, that part of a leak detector tube in which tracer gas is ionized preliminary to being detected

ionization potential — the minimum energy, expressed in (electron) volts, required to remove an electron from an atom or molecule to form a positive ion

ionization vacuum gage — a vacuum gage comprising a means of ionizing the gas molecules, electrodes to facilitate the collection of the positive ions formed, and means of indicating the magnitude of the collected ion current. Various types of ionization gages are distinguished according to the method of producing the ionization. The common types are as follows:

(a) hot-cathode ionization gage — the ions are produced by collisions with electrons emitted from a hot filament (or cathode) and accelerated by an electric field. Also called hot-filament ionization gage, or simply ion gage. The Bayard-Alpert ionization gage employs a tube with an electrode structure designed to minimize X-ray-induced electron emission from the ion collector.

(b) cold-cathode ionization gage — the ions are produced by a cold-cathode discharge, usually in the presence of a magnetic field which lengthens the path of the electrons between cathode and anode. The discharge tube is a transparent tube in which the color and form of a cold-cathode discharge (without the presence of a magnetic field) gives an indication of the pressure and the nature of the gas. The Phillips ionization gage is a cold-cathode ionization gage in which a magnetic field is directly parallel to the axis of an annular electrode (normally the anode) located between two plate electrodes perpendicular to the axis. Various modifications of the Penning gage are named after the inventors, and certain types are referred to as magnetron vacuum gages.

(c) radioactive ionization gage — the ions are produced by radiations (usually alpha particles) emitted from a radioactive source

isolation test — in leak testing, a method of determining whether a leak is present in a system, or of obtaining an estimate of its magnitude, by observing the rate of rise of pressure in the evacuated system when the system is isolated from the pump. See also *rate of rise.*

Krypton 85 — a tracer gas used to test for leakage when the radioisotope leak test method is used

leak — a hole, or void in the wall of an enclosure, capable of passing liquid or gas from one side of the wall to the other under action of pressure or concentration differential existing across the wall, independent of the quantity of fluid flowing

leak artifact — a device used to introduce gas into a system at a controlled rate, usually 10^{-7} mol/s or less

leak detector — a device for detecting, locating, or measuring, or combination thereof, leakage

leak testing — comprises procedures for detecting or locating or measuring leakage, or combinations thereof

leakage rate — the flow rate of a liquid or gas through a leak at a given temperature as a result of a specified pressure difference across the leak. Standard conditions for gases are 25°C and 100 kPa. Leakage rates are expressed in various units such as pascal cubic metres per second or pascal litres per second (see Table 3).

TABLE 3
CONVERSION FACTORS FOR LEAK TESTING

To Convert from	To	Multiply Column 1 by
Leakage Rate:		
atm·cm³/s	Pa·m³/s	1.10×10^{-1}
micron·litres/s	Pa·m³/s	1.33×10^{-4}
micron·ft³/h	Pa·m³/s	1.05×10^{-4}
pascal·litres/s	Pa·m³/s	1.00×10^{-3}
STD·cm³/s	Pa·m³/s	1.01×10^{-1}
torr·litres/s	Pa·m³/s	1.33×10^{-1}
Pressure:		
atmosphere (std)	Pa	1.01×10^{5}
bar	Pa	1.00×10^{5}
micrometre of Hg	Pa	1.33×10^{-1}
micron	Pa	1.33×10^{-1}
millimetre of Hg	Pa	1.33×10^{2}
pounds·force/in.²	Pa	6.89×10^{3}
torr*Viscosity:*	Pa	1.33×10^{2}
centipoise	Pa·s	1.00×10^{-3}
poise	Pa·s	1.00×10^{-1}
Volume:		
cm³	m³	1.00×10^{-4}
ft³	m³	2.83×10^{-2}
litre	m³	1.00×10^{-3}

low vacuum — see Table 2

lusec — a unit of flow rate equal to 0.133 mPa · m³/s

masking — in leak testing, the covering of a section of a test object so as to prevent tracer gas from entering leaks that may exist in the covered section

mass number — the whole number nearest to the atomic mass expressed in either atomic mass units or as (chemical) atomic weight

mass spectrometer (M.S.) — an instrument that is capable of separating ionized molecules of different mass to charge ratio and measuring the respective ion currents. The mass spectrometer may be used as a vacuum gage that relates an output which is proportioned to the partial pressure of a specified gas, as a leak detector sensitive to a particular tracer gas, or as an analytical instrument to determine the percentage composition of a gas mixture. Various types are distinguished by the method of separating the ions. The principal types are as follows:

(a) Dempster (M.S.) — The ions are first accelerated by an electric field through a slit, and are then deflected by a magnetic field through 180 deg. so as to pass through a second slit.

(b) Bainbridge-Jordan (M.S.) — The ions are separated by means of a radial electrostatic field and a magnetic field deflecting the ions through 60 deg. so arranged

that the dispersion of ions in the electric field is exactly compensated by the dispersion in the magnetic field for a given velocity difference.

(c) Bleakney (M.S.) — The ions are separated by crossed electric and magnetic fields. Also called cross fields (M.S.).

(d) Nier (M.S.) — A modification of the Dempster (M.S.) in which the magnetic field deflects the ions.

(e) Time of Flight (M.S.) — The gas is ionized by a pulse-modulated electron beam and each group of ions is accelerated toward the ion collector. Ions of different mass to charge ratios traverse their paths in different times.

(f) Radio-Frequency (M.S.) — The ions are accelerated into a radio-frequency analyzer in which ions of a selected mass to charge are accelerated through openings in a series of spaced plates alternately attached across a radio-frequency oscillator. The ions emerge into an electrostatic field which permits only the ions accelerated in the analyzer to reach the collector.

(g) Omegatron (M.S.) — The ions are accelerated by the cyclotron principle.

mass spectrometer leak detector — a mass spectrometer adjusted to respond only to the tracer gas

mass spectrum — a record, graph, table, etc., that shows the relative number of ions of various mass that are produced when a given substance is processed in a mass spectrometer

mean free path — the average distance that a molecule travels between successive collisions with other molecules

medium vacuum — see Table 2

micrometre — a unit of length equal to one millionth of a metre

micron — a term for micrometre

micron of mercury — a unit of pressure equal to that exerted by a column of mercury standing one micrometre high

millimetre of mercury — a unit of pressure corresponding to a column of mercury exactly 1 mm high under standard acceleration of gravity. Sometimes called torr.

minimum detectable leakage rate — the magnitude of the smallest leakage rate that can be unambiguously detected by a given leak detector in the presence of conditions existing at time of test

molecular flow — the flow of gas through a passage under conditions such that the mean-free path is greater than the largest dimension of a transverse section of the passage

molecular leak — a leak of such geometric configuration that gas flow through it obeys the laws of molecular flow (Knudsen's law). The flow is proportional to the difference of the end pressures and inversely proportional to the square root of the molecular weight of the gas.

newton (N) — the SI unit of force ($kg \cdot m/s^2$)

noncondensable gas — a gas whose temperature is above its critical temperature, so that it cannot be liquefied by increase of pressure alone

occlusion — the trapping of undissolved gas in a solid during solidification

outgassing — the evolution of gas from a material in a vacuum.

outlet pressure — see *forepressure*

palladium barrier leak detector — a leak detector using hydrogen as the tracer gas and using the principle of hydrogen diffusing through a hot palladium barrier into an evacuated vacuum gage

partial pressure — the pressure caused by a gas, either by itself, or in the presence of other gases. When a second gas is not present, the partial pressure is the same as the total pressure.

pascal (Pa) — one pascal is approximately equal to 1×10^{-5} atm or, more precisely, 1 Pa = 0.98692×10^{-5} atm

pascal cubic metres per second ($Pa \cdot m^3/s$) — the preferred unit of gas flow in the SI system. One $Pa \cdot m^3/s$ is approximately equal to 10 atm cm^3/s or, more precisely, 1 $Pa \cdot m^3/s$ = 9.8692 $atm \cdot cm^3/s$.

Penning gage — see *ionization vacuum gage*

perfect gas — see *ideal gas*

permeability coefficient — the steady-state rate of flow of gas through unit area and thickness of a solid barrier per unit pressure differential at a given temperature

Phillips ionization gage — see *ionization vacuum gage*

Pirani gage — see thermal conductivity vacuum gage

Poiseuille flow — the particular case of laminar viscous flow through a long pipe of circular cross section

pressure difference — in leak testing, the difference between the pressure on the inlet side of the leak and the pressure on the exit side of the leak

pressure dye test — *(1)* a form of leak test in which the item or items to be tested are filled with a liquid dye or fluorescent oil which is then pressurized for the purpose of driving the liquid through possible leakage paths with the presence of the leaks being visible when viewed from the exterior; *(2)* a form of leak test in which the item or items to be tested are immersed in a liquid dye or fluorescent oil which is then pressurized for the purpose of driving liquid into possible leakage paths with their presence being visible when the excess liquid has been removed from the exterior.

pressure-evacuation test — a leak test in which one or more devices are placed under gas pressure for a period of time, the objective being to accumulate enough gas in those devices that may leak to permit an indication on a leak detector sensitive to the gas when the devices are placed in an evacuated system joined to the leak detector

pressure probe — see *probe*

pressure testing — a method of leak testing in which the component being tested is filled completely with a gas or liquid which is then pressurized. The outside of the component is examined for the detection of any leaks.

probe — in leak testing, a tube having an opening at one end, used for directing or collecting a stream of tracer gas

probe gas — in leak testing, a tracer gas which issues from an orifice so as to impinge on a restricted test area

probe test — a leak test in which the tracer gas is applied by means of a probe so that the area covered by the tracer gas is localized. This enables the individual leaks to be located.

proportioning probe — in leak testing, a probe that can vary sample to pure air ratios between 100% sample and 100% pure air without substantially changing the total flow from the probe

pump-down time — time of evacuation

pump-out tubulation — a tube extending from an evacuated device through which gas is pumped and which is usually permanently sealed off after the device has been evacuated. Sometimes called exhaust tubulation.

radioisotope leak test system — a leak test system which uses a radioactive tracer gas and a detector for measuring the emission from the tracer

rate of rise — in leak testing, the time rate of pressure increase at a given time in a vacuum system which is suddenly isolated from the pump by a valve. The volume and temperature of the system are held constant during the rate of rise measurement. See *isolation test.*

resistance (to flow) — the reciprocal of conductance

response factor — in leak testing, the response of the halogen leak detector 0.3 MPa · m^3/s of refrigerant-12 (dichloro-difluoromethane, CC12F2) or less, divided by the response to the same quantity of another halogen test gas. Thus, the actual leak rate of a detected leak will be the indication of the detector multiplied by the response factor. The response of mixture of a tracer and nonhalogen gases will be the response factor of the tracer divided by the fraction of tracer gas in the test gas.

response time — the time required for a leak detector or leak testing system to yield a signal output equal to 63% of the maximum signal attained when tracer gas is applied continuously to the system under test. Also called response.

roughing — in leak testing, the initial evacuation of a vacuum system

roughing line — in leak testing, a line running from a mechanical pump to a vacuum chamber through which preliminary pumping is conducted in the rough vacuum range

roughing pump — in leak testing, a vacuum pump used for the initial evacuation of a vacuum system

sampling probe — in leak testing, a device used to collect tracer gas from an area of the test object and feed it to the leak detector at the reduced pressure required. Also called a sniffing probe.

scattering — in leak testing, dispersion or diffusion in various directions due to intermolecular or ionic collisions as applied to the effect of the residual gas in a mass spectrometer tube or an ion beam traversing the tube

search-gas — same as *tracer gas*

sensitivity — in the case of a leak detector, the response of the detector to tracer gas leakage (that is, scale divisions per unit of leakage rate)

sensitivity of leak test — the smallest leakage rate that an instrument, method, or system is capable of detecting under specified conditions. See *minimum detectable leakage rate.*

sniffing probe — same as *sampling probe*

sorption — the taking up of gas by absorption, adsorption, chemisorption, or any combination of these processes

spark coil leak detector — a high-frequency discharge coil of the Tesla type which indicates pin holes in glass vacuum systems by a spark jumping between the core of the coil and the pin hole

spectrometer tube — the sensing element of a mass spectrometer leak detector

spray probe — in leak testing, a device for directing a small jet of tracer gas on an object under vacuum testing

squealer — same as *audible leak indicator*

standard leak — a device that permits a tracer gas to be introduced into a leak detector or leak testing system at a known rate to facilitate calibration of the leak detector

standard leakage rate — the rate of flow of atmospheric air under conditions in which: inlet pressure is 0.1 MPa ± 5%; outlet pressure is less than 1 kPa; temperature is 25°C ± 5°C; and dew point is less than −25°C.

thermal conductivity vacuum gage — a vacuum gage containing two surfaces at different temperatures between which heat can be transported by the gas molecules so that changes in the temperature (or in the heating power required to maintain constant temperature) of one of the surfaces can be correlated with the gas pressure. Various types of thermal conductivity gages are distinguished according to the method of indicating the temperature change. The common types are listed below:

(a) Pirani Gage. An increase of pressure from the zero point causes a decrease in the temperature of a heated filament of material having a large temperature coefficient of resistance thus unbalancing a Wheatstone bridge circuit (or the circuit is adjusted to maintain the filament temperature constant).

(b) Thermocouple Gage. The decrease in temperature of a heated filament as the pressure rises is indicated by decreased emf in a thermocouple circuit having the junction in thermal contact with the center of the heated filament.

(c) Thermistor Gage. A form of Pirani gage employing a thermistor as the heated element.

(d) Bimetallic Strip Gage. Deflection of a bimetallic strip with changing temperature indicates the changes in pressure.

thermocouple gage — see *thermal conductivity vacuum gage*

throttling — in leak testing, reducing the net pumping speed of a pumping system by partially closing a valve or installing a section of pipeline with low conductance

throughput — same as *flow rate (1).*

tight — in leak testing, free from leaks according to a given specification

torr — a unit of pressure equal to 1/760th of an atmosphere

tracer gas — a gas which, passing through a leak, can then be detected by a specific leak detector and thus disclose the presence of a leak. Also called search gas.

tracer probe leak location — same as *probe test.*

transition flow — in leak testing, the flow of gases under conditions intermediate between laminar viscous flow and molecular flow

ultra-high vacuum — see Table 2

ultrasonic leak detector — an instrument that detects ultrasonic energy produced by molecular turbulence that occurs in the transition from laminar to turbulent flow of a gas through an orifice and that converts this energy to a usable signal

vacuum — in vacuum technology, a given space filled with gas at pressures below atmospheric pressure (see Table 2)

vacuum testing — *(1)* a method of testing for leaks in which the object under test is evacuated and the tracer gas applied to the outside surface of the object; *(2)* a leak-testing procedure in which the enclosure under examination is evacuated, the tracer gas applied to the outside surface of the enclosure, and the gas detected after entering the enclosure.

vapor pressure — the pressure exerted by the vapor of a solid or liquid when in equilibrium with the solid or liquid

very high vacuum — see Table 2

virtual leak — *(1)* the semblance of a leak in a vacuum system caused by slow release of trapped gas. *(2)* during a rate-of-rise test, the semblance of a leak in a vacuum system caused by slow release of sorbed or occluded gas or gases on or in the surfaces and pores of all materials in a system which has been exposed to atmospheric pressure prior to evacuation.

viscous flow — the flow of gas through a duct under conditions such that the mean free path is very small in comparison with the smallest dimension of a transverse section of the duct. This flow may be either laminar or turbulent.

viscous leak — a leak of such geometric configuration that gas flow through it is viscous in nature; that is, the

flow obeys Poiseuille's Law. The flow rate is proportional to the difference of the squares of the end pressures, and inversely proportional to the gaseous viscosity.

9. Liquid Penetrant Examination

angstrom unit (Å) — a unit of length which may be used to express the wavelength of electromagnetic radiation, that is, light. One angstrom unit is equal to 0.1 nanometres. (1 nm = 10^{-9} m.)

background — the surface of the test part against which the indication is viewed. It may be the natural surface of the test part or the developer coating on the surface.

black light — electromagnetic radiation in the near-ultraviolet range of wavelength. (330–390 nm) (3300–3900 Å)

black light filter — a filter that transmits near-ultraviolet radiation while absorbing other wavelengths

bleedout — the action of an entrapped liquid penetrant in surfacing from discontinuities to form indications

blotting — the action of the developer in soaking up the penetrant from the discontinuity to accelerate bleedout

carrier — a liquid, either aqueous or nonaqueous, in which liquid penetrant examination materials are dissolved or suspended

clean — free of contaminants

contaminant — any foreign substance present on the test surface or in the inspection materials which will adversely affect the performance of liquid penetrant materials

contrast — the difference in visibility (brightness or coloration) between an indication and the background

detergent remover — a penetrant remover that is a solution of a detergent in water

developer — a material that is applied to the test surface to accelerate bleedout and to enhance the contrast of indications

developer, aqueous — a suspension of developer particles in water

developer, dry powder — a fine free-flowing powder used as supplied

developer, liquid film — a suspension of developer particles in a vehicle which leaves a resin/polymer film on the test surface after drying

developer, nonaqueous — developer particles suspended in a nonaqueous vehicle prior to application

developer, soluble — a developer completely soluble in its carrier, not a suspension of powder in a liquid, which dries to an absorptive coating

developing time — the elapsed time between the application of the developer and the examination of the part

dragout — the carryout or loss of penetrant materials as a result of their adherence to the test pieces

drain time — that portion of the dwell time during which the excess penetrant or emulsifier drains from the part

drying oven — an oven used for increasing the evaporation rate of rinse water or an aqueous developer vehicle from test parts

drying time — the time required for a cleaned, rinsed, or wet developed test part to dry

dwell time — the total time that the penetrant or emulsifier is in contact with the test surface, including the time required for application and the drain time

electrostatic spraying — a technique for attaining a uniform coating in which the material sprayed is given an electrical charge

eluant — a liquid used to extract one material from another, as in chromatography

emulsification time — the time that an emulsifier is permitted to remain on the part to combine with the surface penetrant prior to removal. Also called emulsification dwell time.

emulsifier — a liquid that interacts with an oily substance to make it water-washable

emulsifier, hydrophilic — a water-based liquid used in penetrant examination which interacts with the penetrant oil, rendering it water-washable

emulsifier, lipophilic — an oil based liquid used in penetrant examination which interacts with the penetrant oil, rendering it water-washable

etching — the removal of surface material by chemical or electrochemical methods

family — a complete series of penetrant materials required for the performance of a liquid penetrant examination

fluorescence — the emission of visible radiation by a substance as a result of, and only during, the absorption of black light radiation

footcandle (fc) — the illumination on a surface, 1 ft^2 in area, on which is uniformly distributed a flux of 1 lm (lumen). It equals 10.8 lm/m^2.

hydrophilic emulsifier — see *emulsifier*

immersion rinse — a means of removing surface penetrant, in which the test part is immersed in a tank of either water or remover

immersion rinse — a means of removing excess penetrant in which the test parts are dipped into an agitated tank of water or remover

inspection — visual examination of the test part after completion of the liquid penetrant processing steps

lipophilic emulsifier — see *emulsifier lipophilic*

liquid penetrant examination — a nondestructive test that uses suitable liquids that penetrate discontinuities open to the surface of solid materials and, after appropriate treatment, indicate the presence of discontinuities

overemulsification — excessive emulsifier dwell time which results in the removal of penetrants from some discontinuities

overwashing — too long or too vigorous washing, or both, which results in removal of penetrants from some discontinuities

penetrant — a solution or suspension of dye

penetrant comparator — an intentionally flawed specimen having separate but adjacent areas for the application of different liquid penetrant materials so that a direct comparison of their relative effectiveness can be obtained

NOTE 22 — It can also be used to evaluate liquid penetrant techniques, liquid penetrant systems, or test conditions.

penetrant, fluorescent — a penetrant that emits visible radiation when excited by black light

penetrant, post emulsifiable — a liquid penetrant that requires the application of a separate emulsifier to render the excess surface penetrant water-washable

penetrant, solvent-removable — a liquid penetrant so formulated that most of the excess surface penetrant can be removed by wiping with a lint-free material, with the remaining surface penetrant traces removable by further wiping with a lint-free material lightly moistened with solvent remover

penetrant, visible — a liquid penetrant that is characterized by an intense color, usually red

penetrant, water-washable — a liquid penetrant with a built-in emulsifier

penetration time — same as *dwell time*

pooling — the existence of excessive amounts of penetrant, emulsifier, or developer in an incompletely drained area

post-cleaning — the removal of residual liquid penetrant examination materials from the test part after the penetrant examination has been completed

post emulsification — a penetrant removal technique employing a separate emulsifier

precleaning — the removal of surface contaminants from the test part so that they will not interfere with the examination process

rinse — the process of removing liquid penetrant examination materials from the surface of a test part by means of washing or flooding with another liquid, usually water. The process is also termed *wash.*

solvent remover — a volatile liquid penetrant used to remove excess penetrant from the surface being examined

temperature envelope — the temperature range over which a particular penetrant inspection test will operate

viscosity — the property of a fluid that presents a resistance to shearing flow

visible light — electromagnetic radiation in the 400–700 (4000–7000 Å) wavelength range

visual adaptation — the adjustment of the eyes when one passes from a bright to a darkened place

wash — same as *rinse*

water tolerance — the amount of water that a penetrant or emulsifier can absorb before its effectiveness is impaired

wetting action — the ability of a liquid to spread over and adhere to solid surfaces

10. Magnetic Particle Examination

ammeter shunt — a low-resistance precision resistor with high current carrying capacity connected in parallel with an ammeter

ampere turns — the product of the number of turns of a coil and the current in amperes flowing through the coil

arc strikes — localized burn damage to a part from an arc caused by making or breaking an energized electrical circuit

background — in magnetic particle examination, the appearance of the surface of the test part against which indications are viewed

bath — see *suspension*

bipolar field — see *field, bipolar*

black light — electromagnetic radiation in the near ultraviolet range of wavelength (330 to 390 nm) (3300 to 3900 Å)

black light filter — a filter that transmits near ultraviolet radiation while absorbing other wavelengths

carrier fluid — the fluid in which fluorescent and nonfluorescent magnetic particles are suspended to facilitate their application

central conductor — a conductor passed through a hollow part and used to produce circular magnetization within the part

circular field — see *field, circular*

circular magnetization — the magnetization in a part resulting from current passed directly through the part or through a central conductor

coercive force — the magnetizing force at which the magnetic flux density is equal to zero. The corresponding field intensity value is indicative of the ease of difficulty or demagnetization.

coil method — a method of magnetization in which part, or whole, of the component is encircled by a current-carrying coil

coil technique — a technique of magnetization in which all, or a portion, of the part is encircled by a current-carrying coil

conditioning agent — an additive to a water suspension that will impart specific properties such as proper wetting, particle dispersion, or corrosion resistance

contact head — electrode assembly used to clamp and support a part to facilitate passage of electrical current through the part for circular magnetization

contact pad — replaceable metal pad, usually of copper braid, placed on electrodes to give good electrical contact, thereby preventing damage, such as arc strikes, to the part under test

continuous method — with relation to magnetic particle inspection: a method wherein the indicating medium is applied while the magnetizing force is present.

core (of an electromagnetic inspection circuit) — that part of the magnetic circuit which is within the electrical winding

Curie point — the temperature at which ferromagnetic materials can no longer be magnetized by outside forces, and at which they lose their residual magnetism [approximately 1,200 to 1,600°F (649 to 871°C) for many metals]

current flow method — a method of magnetizing by passing a current through a component via prods or contact heads. The current may be alternating, rectified alternating, or direct.

current induction method — a method of magnetizing in which a circulating current is induced in a ring component by the influence of a fluctuation magnetic field that links the component

dark adaptation — the adjustment of the eyes when one passes from a bright to a darkened place

demagnetization — the reduction of residual magnetism to an acceptable level

diffuse indications — indications that are not clearly defined as, for example, indications of subsurface defects

direct contact magnetization — a technique of magnetizing in which the current is passed through a part via prods or contact heads

dry method — magnetic particle inspection in which the ferromagnetic particles employed are in the dry powder form

dry powder — finely divided ferromagnetic particles suitably selected and prepared for magnetic particle inspection

dry technique — in magnetic particle examination, the examination technique in which the ferromagnetic particles are applied in the dry powder form

electromagnet — a soft iron core surrounded by a coil of wire that temporarily becomes a magnet when an electric current flows through the wire

energizing cycle — the application of a magnetizing force to a conductor

examination medium — a powder or suspension of magnetic particles that is applied to a magnetized test surface

to determine the presence or absence of surface or slightly subsurface discontinuities

ferromagnetic — a term applied to materials that can be magnetized or strongly attracted by a magnetic field

field, bipolar — longitudinal magnetic field within a part that has two poles

field, circular magnetic — generally, the magnetic field surrounding any electrical conductor or part resulting from a current being passed through the part or conductor from one end to another

field, longitudinal magnetic — magnetic field wherein the flux lines traverse the component in a direction essentially parallel with its longitudinal axis

field, magnetic — the space, within and surrounding a magnetized part or a conductor carrying current, in which the magnetic force is exerted

field, magnetic leakage — the magnetic field that leaves or enters the surface of a part at a discontinuity or change in section configuration of a magnetic circuit

field, residual magnetic — the field that remains in a piece of magnetizable material after the magnetizing force has been removed

field, resultant magnetic — (sometimes called vector): a magnetic field that is the result of two magnetizing forces impressed upon the same area of a magnetizable object

field strength — see *magnetic field strength*

fill factor — in magnetic particle examination, the ratio of the cross-sectional area of the part being tested to the cross-sectional area of the encircling coil

flash magnetization — magnetization by a current flow of very brief duration

flash point — the lowest temperature at which vapors above a volatile combustible substance ignite in air when exposed to a flame

fluorescence — the emission of visible radiation by a substance as the result of, and only during, the absorption of black light radiation

fluorescent examination method — the magnetic particle examination method employing a finely divided fluorescent ferromagnetic inspection medium

fluorescent magnetic particle inspection — the magnetic particle inspection process employing a finely divided fluorescent ferromagnetic inspection medium that fluoresces when activated by black light [3200 to 4000 Å (320 to 400 nm)]

flux density, magnetic — the strength of a magnetic field, expressed in flux lines per unit area

flux leakage field — the magnetic field that leaves or enters the surface of a part as the result of a discontinuity or a change in section

flux lines — see *lines of force*

flux penetration — the depth to which a magnetic flux exists in a part

full-wave direct current (FWDC) — a rectified three-phase alternating current

furring — buildup or bristling of magnetic particles due to excessive magnetization of the component under examination resulting in a furry appearance

gaussmeter, n — a device that measures magnetic flux density or magnetic induction (a quantity directly related to magnetic field strength or magnetic force); also known as a Tesla Meter or Magnetometer

gaussmeter (electronic), n — a gaussmeter that uses a hall effect probe to measure magnetic flux density

half-wave current (HW) — a rectified single-phase alternating current that produces a pulsating unidirectional field

hall effect — a phenomenon in which a transverse electric field is produced in a current-carrying conductor placed in a magnetic field

hysteresis — *(1)* the lagging of the magnetic effect when the magnetic force acting upon a ferromagnetic body is changed *(2)* the phenomenon exhibited by a magnetic system wherein its state is influenced by its previous history

indirect magnetization — magnetization induced in a part when no direct electrical contact is made

induced current method — see *current induction method*

induced field — see *indirect magnetization*

inherent fluorescence — fluorescence that is an intrinsic characteristic of a material

inspection medium — see *examination medium*

leakage field — see *field, magnetic leakage*

leeches — permanent magnets or electromagnets that are attached to the electrodes carrying magnetizing current and that are strong enough to hold electrode contact firmly

light intensity — the light energy reaching a unit area of surface per unit time

lines of force — a conceptual representation of magnetic flux based upon the line pattern produced when iron filings are sprinkled on paper laid over a permanent magnet

local magnetization — magnetization of a prescribed volume or surface of a part

longitudinal magnetization — a magnetic field wherein the lines of force traverse the part in a direction essentially parallel with its longitudinal axis

magnet, permanent — see *permanent magnet*

magnetic field — the volume within and surrounding either a magnetized part or a current-carrying conductor wherein a magnetic force is exerted

magnetic field indicator — a pocket meter that is used to locate or determine the relative intensity of leakage field emanating from a part

magnetic field meter — an instrument designed to measure the flux density of magnetic fields

magnetic field strength — the measured intensity of a magnetic field at a point, expressed in oersteds or amperes per metre

magnetic hysteresis — in a magnetic material, as iron, a lagging in the values of resulting magnetization due to a changing magnetic force. (See also *hysteresis.*)

magnetic particle examination — a nondestructive test method utilizing magnetic leakage fields and suitable indicating materials to disclose surface and near-surface discontinuity indications

magnetic particle examination flaw indications — the accumulation of ferromagnetic particles along the areas of flaws or discontinuities due to the distortion of the magnetic lines of force in those areas

magnetic particle field indicator — an instrument, typically a bi-metal (for example, carbon steel and copper) octagonal disk, containing artificial flaws used to verify the adequacy or direction, or both, of the magnetizing field

magnetic particles — finely divided ferromagnetic material capable of being individually magnetized and attracted to distortion in a magnetic field

magnetic pole — one of two or more areas of flux leakage on a part

magnetic writing — a form of nonrelevant indication sometimes caused when the surface of a magnetized part comes in contact with another piece of ferromagnetic material

magnetization, circular — see *field, circular*

magnetization, longitudinal — see *field, longitudinal*

magnetizing current — the flow of either alternating or direct current used to induce magnetism into the part being inspected

magnetizing force — the magnetizing field applied to a ferromagnetic material to induce magnetization

multidirectional magnetization — the alternative application of magnetic fields in different directions during the same time frame

near surface discontinuity — a discontinuity not open to, but lying near, the surface of a part undergoing examination which produces broad, fuzzy, lightly held powder patterns

overall magnetization — magnetization of an entire part with a single energizing cycle

permanent magnet — a magnet that retains a high degree of magnetization virtually unchanged for a long period of time (characteristic of materials with high retentivity)

permeability — the ratio of flux density produced to magnetizing force (the ease with which a material can become magnetized)

pole — the area on a magnetized part from which the magnetic field is leaving or returning into the part

polymer technique — the examination technique in which a polymer is used as the particle suspension vehicle

powder — see *dry powder*

powder blower — a compressed air device used to apply magnetic powder over the surface of a part undergoing inspection

prods — hand-held electrodes

quick break — a sudden interruption of the magnetizing current

residual magnetic field — the field that remains in ferromagnetic material after the magnetizing force has been removed

residual technique — the application of the magnetic particles after the magnetizing force has been discontinued

resultant field — see *field, resultant*

retentivity — the ability of a material to retain a portion of the applied magnetic field after the magnetizing force has been removed

saturation, magnetic — the total magnetization produced in a ferromagnetic material, at which point the incremental permeability has progressively decreased to approach unity

sensitivity — the degree of capability of a magnetic particle examination technique for indicating surface or near surface discontinuities in ferromagnetic materials

shot — a short energizing cycle in a magnetic particle examination

skin effect — the phenomenon that causes the magnetization produced by alternating current to be contained near the surface of a ferromagnetic part

solenoid — an electrical conductor formed into a coil

subsurface discontinuity — any defect that does not open onto the surface of the part in which it exists

surge magnetization — use of a high initial current for a short period (less than a second), then a continuous reduced current while the inspection medium is applied

suspension — a two-phase system consisting of a finely divided solid dispersed in a liquid

swinging field — see *multidirectional magnetization*

test piece — a specimen containing known artificial or natural defects used for checking the efficiency of magnetic particle flaw detection processes

test ring — a ring specimen containing artificial subsurface discontinuities which is used to evaluate and compare the overall performance and sensitivity of magnetic particle examination techniques

through-coil technique — see *coil technique*

true continuous technique — magnetic particle examination in which the magnetizing current is applied prior to the application of the magnetic particles and is maintained without interruption throughout the examination

vehicle — a liquid medium for the suspension of magnetic particles

visible light — radiant energy generated in 400 to 700 nm (4000 to 7000 Å) wavelength range

water break test — a quality control test of conditioned water

wet slurry technique — a magnetic particle examination technique in which the magnetic particles are suspended in a high-viscosity vehicle

wet technique — the examination technique in which the magnetic particles are suspended in a liquid vehicle

white light — see *visible light*

yoke — a magnet that induces a magnetic field in the area of a part that lies between its poles. Yokes may be permanent magnets or either alternating-current or direct-current electromagnets

yoke magnetization — a longitudinal magnetic field induced in a part, or in an area of a part, by means of an external electromagnet shaped like a yoke

11. Neutron Radiology

activation — the process of causing a substance to become artificially radioactive by subjecting it to bombardment by neutrons or other particles

attenuation coefficient — related to the rate of change in the intensity of a beam of radiation as it passes through matter. See *linear and mass attenuation coefficient.*

attenuation cross section — the probability, expressed in barns, that a neutron will be totally absorbed by the atomic nucleus

barn — a unit of area used for expressing the area of nuclear cross sections: 1 barn = 10^{-24} cm^2.

cadmium ratio — the ratio of the neutron reaction rate measured with a given bare neutron detector to the reaction rate measured with an identical neutron detector enclosed by a particular cadmium cover and exposed in the same neutron field at the same or an equivalent spatial location

NOTE 23 — In practice, meaningful experimental values can be obtained in an isotropic neutron field by using a cadmium filter approximately 1-mm thick.

cassette — a light-tight device for holding film or conversion screens and film in close contact during exposure

contrast agent — a material added to a component to enhance details by selective absorption of the incident radiation

conversion screen — a device that converts the imaged neutron beam to radiation or light that exposes the radiographic film

cross section — the apparent cross-sectional area of the nucleus as calculated on the basis of the probability of occurrence of a reaction by collision with a particle. It does not necessarily coincide with the geometrical cross-sectional area πr^2. It is given in units of area, 1 barn = 10^{-24} cm^2.

direct exposure imaging — in the direct exposure imaging method, the conversion screen and image recorder are simultaneously exposed to the neutron beam

electron volt — the kinetic energy gained by an electron after passing through a potential difference of 1 V

facility scattered neutrons — neutrons scattered in the facility that contribute to the film exposure

γ — effective gamma content. γ is the percent background film darkening caused by low-energy photon radiation absorbed by pair production in 2 mm of lead

gamma ray — electromagnetic radiation having its origin in an atomic nucleus

half-life — the time required for one half a given number of radioactive atoms to undergo decay

half-value layer — the thickness of an absorbing material required to reduce the intensity of a beam of incident radiation to one-half of its original intensity

image quality indicator — a device or combination of devices whose image or images on a neutron radiograph provide visual or quantitative data, or both, concerning the radiographic sensitivity of the particular neutron radiograph

indirect exposure — a method in which only a gamma-insensitive conversion screen is exposed to the neutron beam. After exposure, the conversion screen is placed in contact with the image recorder.

L/D ratio — one measure of the resolution capability of a neutron radiographic system. It is the ratio of the distance between the entrance aperture and the image plane (L) to the diameter of the entrance aperture (D).

linear attenuation coefficient — a measure of the fractional decrease in radiation beam intensity per unit of distance traveled in the material (cm^{-1})

low-energy photon radiation — gamma- and X-ray photon radiation having energy less than 200 keV (excluding visible and ultraviolet light)

mass attenuation coefficient — a measure of the fractional decrease in radiation beam intensity per unit of surface density $cm^2 \cdot gm^{-1}$

moderator — a material used to slow fast neutrons. Neutrons are slowed down when they collide with atoms of light elements such as hydrogen, deuterium, beryllium, and carbon

NC — effective thermal neutron content or neutron radiographic contrast. NC is the percent background film exposure due to unscattered thermal neutrons.

neutron — a neutral elementary particle having an atomic mass close to 1. In the free state outside of the nucleus, the neutron is unstable having a half-life of approximately 10 min.

neutron radiography — the process of producing a radiograph using neutrons as the penetrating radiation

object scattered neutrons — neutrons scattered by the test objects that contribute to the film exposure

P — effective pair production content. P is the percent background exposure caused by pair production in 2 mm of lead.

pair production — the process whereby a gamma photon with energy greater than 1.02 MeV is converted directly into matter in the form of any electron-positron pair. Subsequent annihilation of the positron results in the production of two 0.511 MeV gamma photons.

process control radiograph — a radiograph which images a beam purity indicator and sensitivity indicator under identical exposure and processing procedures as the test object radiograph. A process control radiograph may be used to determine image quality parameters in circumstances of large or unusual test object geometry.

radiograph — a permanent, visible image on a recording medium produced by penetrating radiation passing through the material being tested

radiographic inspection — the use of X rays or nuclear radiation, or both, to detect discontinuities in material, and to present their images on a recording medium

radiography — the process of producing a radiograph using penetrating radiation

radiological examination — the use of penetrating ionizing radiation to display images for the detection of discontinuities or to help ensure integrity of the part

radiology — the science and application of X-rays, gamma rays, neutrons, and other penetrating radiations

radioscopic inspection — the use of penetrating radiation and radioscopy to detect discontinuities in material

radioscopy — the electronic production of a radiological image that follows very closely the changes with time of the object being imaged

real-time radioscopy — radioscopy that is capable of following the motion of the object without limitation of time

S — effective scattered neutron content. *S* is the percent background film darkening caused by scattered neutrons.

scattered neutrons — neutrons that have undergone a scattering collision but still contribute to film exposure

sensitivity value — the value determined by the smallest standard discontinuity in any given sensitivity indicator observable in the radiographic image. Values are defined by identification of type of indicator, size of defect, and the absorber thickness on which the discontinuity is observed.

thermalization — the process of slowing neutron velocities by permitting the neutrons to come to thermal equilibrium with a moderating medium

thermalization factor — the inverse ratio of the thermal neutron flux obtained in a moderator, per source neutron

thermal neutrons — neutrons having energies ranging between 0.005 eV and 0.5 eV; neutrons of these energies are produced by slowing down fast neutrons until they are in equilibrium with the moderating medium at a temperature near 20°C.

total cross section — the sum of the absorption and scattering cross sections

vacuum cassette — a light-tight device having a flexible entrance window, which when operated under a vacuum, holds the film and conversion screen in intimate contact during exposure

12. Ultrasonic Examination (E 127, E 494, E 664, and E 804)

A-scan — a method of data presentation utilizing a horizontal baseline that indicates distance, or time, and a vertical deflection from the baseline which indicates amplitude

amplitude — the vertical pulse height of a signal, usually base to peak, when indicated by an A-scan presentation

angle beam — a term used to describe an angle of incidence or refraction other than normal to the surface of the test object, as in angle beam examination, angle beam search unit, angle beam longitudinal waves, and angle beam shear waves

apparent attenuation — the observed ultrasound energy loss. In addition to the true loss, the apparent attenuation may also include losses attributable to instrumentation, specimen configuration, beam divergence, interface reflections, and measurement procedure. (E 664)

area amplitude response curve — a curve showing the changes in amplitude at normal incidence from planar reflectors of different areas located at equal distances from the search unit in an ultrasonic-conducting medium

attenuation — a factor that describes the decrease in ultrasound intensity with distance. Normally expressed in decibel per unit length.

NOTE 24 — The attenuation parameter is sometimes expressed in nepers (Np) per unit length. The value in decibels (dB) is 8.68 times the value in nepers. If the loss over a path is 1 Np, then the amplitude has fallen to 1/e of its initial value (e = 2.7183. . .). (E 664)

attenuator — a device for altering the amplitude of an ultrasonic indication in known increments, usually decibels

B-scan presentation — a means of ultrasonic data presentation which displays a cross section of the specimen indicating the approximate length (as detected per scan) of reflectors and their relative positions

back reflection — indication of the echo from the far boundary of the material under test

back surface — the end of a reference block that is opposite the entry surface (E 127)

base line — the time of flight or distance trace (horizontal) across the A-scan CRT display (for no signal condition)

beam axis — the acoustic centerline of a search unit's beam pattern as defined by the locus of points of maximum sound pressure in the far field, and its extension into the near field

beam spread — a divergence of the ultrasonic beam as the sound travels through a medium

bottom echo — see *back reflection*

bubbler — a device using a liquid stream to couple an ultrasonic beam to the test piece

C-scan — an ultrasonic data presentation which provides a plain view of the test object, and discontinuities therein

collimator — a device for controlling the size and direction of the ultrasonic beam

compressional wave — see *longitudinal wave*

contact testing — a technique in which the search unit makes contact directly with the test piece through a thin layer of couplant

continuous wave — a constant flow of ultrasonic waves, as opposed to pulsed

control echo — reference signal from a constant reflecting surface, such as a back reflection

corner effect — the reflection of an ultrasonic beam directed at normal incidence to the line of intersection of two perpendicular planes

couplant — a substance used between the search unit and test surface to permit or improve transmission of ultrasonic energy

critical angle — the incident angle of the ultrasonic beam beyond which a specific refracted wave no longer exists

cross talk — the signal leakage (acoustic or electric) across an intended acoustic or electric barrier

crystal (see transducer) — the piezoelectric element in an ultrasonic search unit. The term is used to describe single crystal piezoelectrics as well as polycrystalline piezoelectrics, such as ferroceramics.

DAC (distance amplitude correction) (swept gain, time corrected gain, time variable gain, etc.) — electronic change of amplification to provide equal amplitude from equal reflectors at different depths

damping, search unit — limiting the duration of a signal from a search unit subject to a pulsed input by electrically or mechanically decreasing the amplitude of successive cycles

dB control — a control that adjusts the amplitude of the display signal in dB units

dead zone — the distance in the material from the surface of the test object to the depth at which a reflector can first be resolved under specified conditions. It is determined by the characteristics of the search unit, the ultrasonic test instrumentation, and the test object

decibel (dB) — twenty times the base ten logarithm of the ratio of two ultrasonic signal amplitudes: dB = 20 $\log_{10}$ (amplitude ratio)

delayed sweep — an A-scan or B-scan presentation in which an initial part of the time scale is not displayed

DGS (distance gain size-German AVG) — distance amplitude curves permitting prediction of reflector size compared to the response from a back surface reflection

distance amplitude compensation (electronic) — the compensation or change in receiver amplification necessary to provide equal amplitude on the display of the ultrasonic flaw detector for reflectors of equal area which are located at different depths in the material

distance amplitude response curve — a curve showing the relationship between the different distances and the amplitudes of ultrasonic response from targets of equal size in an ultrasonic response from targets of equal size in an ultrasonic transmitting medium (E 127)

distance linearity range — the range of horizontal deflection in which a constant relationship exists between the incremental horizontal displacement of vertical indications on the A-scan presentation and the incremental time required for reflected waves to pass through a known length in a uniform transmission medium (E 494)

dual search unit — a search unit containing two elements: one a transmitter, the other a receiver

dynamic range — a measure of the capability of a test system to accept input signals of varying magnitudes, given by the ratio of the maximum to minimum input signals which at constant gain will produce distortion-free outputs having discernable changes with incremental variations in input

NOTE 25 — Dynamic range may be stated as the numerical value of the ratio, however, this is usually expressed in decibels.

NOTE 26 — When the output indications can be related to the size of recognized targets, such as flat-bottomed holes, dynamic range is sometimes expressed in terms of the maximum and minimum hole sizes that can be displayed.

echo — indication of reflected energy

far field — the zone of the beam where equal reflectors give exponentially decreasing amplitudes with increasing distance

focused beam — converging energy of the sound beam at a specified distance

frequency (fundamental) — in resonance testing, the frequency at which the wave length is twice the thickness of the examined material

frequency (inspection) — effective ultrasonic wave frequency of the system used to inspect the material

frequency (pulse repetition) — the number of times per second an electro-acoustic search unit is excited by the

pulse generator to produce a pulse of ultrasonic energy. This is also called pulse repetition rate.

gap scanning — short fluid column coupling technique

gate — an electronic means of selecting a segment of the time range for monitoring or further processing

grazing incidence — immersion inspection with the beam directed at a glancing angle to the test surface

harmonics — those vibrations which are integral multiples of the fundamental frequency

holography (acoustic) — an inspection system using the phase interface between the ultrasonic wave from an object and a reference signal to obtain an image of reflectors in the material under test

immersion testing — an ultrasonic examination method in which the search unit and the test part are submerged (at least locally) in a fluid, usually water

impedance (acoustic) — a mathematical quantity used in computation of reflection characteristics at boundaries; product of wave velocity and material density

indication — that which marks or denotes the presence of a reflector

initial pulse — the response of the ultrasonic system display to the transmitter pulse (sometimes called main bang)

interface — the boundary between two materials

Lamb wave — a specific mode of propagation in which the two parallel boundary surfaces of the material under examination (such as a plate or the wall of a tube) establish the mode of propagation. The Lamb wave can be generated only at particular values of frequency, angle of incidence, and material thickness. The velocity of the wave is dependent on the mode of propagation and the product of the material thickness and the examination frequency.

linearity (amplitude) — a measure of the proportionality of the amplitude of the signal input to the receiver, and the amplitude of the signal appearing on the display of the ultrasonic instrument or on an auxiliary display

linearity (time or distance) — a measure of the proportionality of the signals appearing on the time or distance axis of the display and the input signals to the receiver from a calibrated time generator or from multiple echos from a plate of material of known thickness

longitudinal wave — those waves in which the particle motion of the material is essentially in the same direction as the wave propagation (E 494)

loss of back reflection — an absence or significant reduction in the amplitude of the indication from the back surface of the part under examination

markers — the electronically generated time pulses or other indicators that are used on the instrument display to measure distance or time

mode — the type of ultrasonic wave propagating in the materials as characterized by the particle motion (for example, longitudinal, transverse, etc.)

mode conversion — phenomenon by which an ultrasonic wave that is propagating in one mode can reflect or refract at an interface to form ultrasonic wave(s) of other modes

multiple back reflections — successive reflections from the back surface of the material under examination

multiple reflections — successive echoes of ultrasonic energy between two surfaces

near field — the region of the ultrasonic beam adjacent to the transducer and having complex beam profiles. Also known as the Fresnel zone.

noise — any undesired signal (electrical or acoustic) that tends to interfere with the reception, interpretation, or processing of the desired signal

normal incidence (also see straight beam) — a condition in which the axis of the ultrasonic beam is perpendicular to the entry surface of the part under examination

penetration depth — the maximum depth in a material from which usable ultrasonic information can be obtained and measured

plate wave — see *Lamb wave*

probe — see *search unit*

pulse — a short wave train of mechanical vibrations

pulse echo method — an inspection method in which the presence and position of a reflector are indicated by the echo amplitude and time

pulse length — a measure of the duration of a signal as expressed in time or number of cycles

pulse repetition rate — see *frequency (pulse repetition)*

pulse tuning — a control used on some ultrasonic examination equipment to optimize the response of the search

unit and cable to the transmitter by adjusting the frequency spectrum of the transmitted pulse

radio frequency (r-f) display — the display of an unrectified signal on the CRT or recorder

range — the maximum sound path length that is displayed

Rayleigh wave — an ultrasonic surface wave in which the particle motion is elliptical and the effective penetration is approximately one wavelength

reference block — a block that is used both as a measurement scale and as a means of providing an ultrasonic reflection of known characteristics

reflection — see *echo*

reflector — an interface at which an ultrasonic beam encounters a change in acoustic impedance and at which at least part of the energy is reflected

reject (suppression) — a control for minimizing or eliminating low amplitude signals (electrical or material noise) so that larger signals are emphasized

resolution — the ability of ultrasonic equipment to give simultaneous, separate indications from discontinuities having nearly the same range and lateral position with respect to the beam axis

resonance method — a technique in which continuous ultrasonic waves are varied in frequency to identify resonant characteristics in order to discriminate some property of a part such as thickness, stiffness, or bond integrity

saturation — a condition in which an increase in input signal produces no increase in amplitude on the display

saturation level — see *vertical limit*

scanning — the movement of a search unit relative to the test piece in order to examine a volume of the material

scanning index — the distance the search unit is moved between scan paths after each traverse of the part

scattered energy — energy that is reflected in a random fashion by small reflectors in the path of a beam of ultrasonic waves

scattering — the dispersion, deflection, or redirection of the energy in an ultrasonic beam caused by small reflectors in the material being examined

Schlieren system — an optical system used for visual display of an ultrasonic beam passing through a transparent medium

SE probe — see *dual search unit (twin probe)*

search unit — an electro-acoustic device used to transmit or receive ultrasonic energy, or both. The device generally consists of a nameplate, connector, case, backing, piezoelectric element, wearface, or lens, or wedge.

sensitivity — a measure of the smallest ultrasonic signal which will produce a discernible indication on the display of an ultrasonic system

shadow — a region in a body that cannot be reached by ultrasonic energy traveling in a given direction because of the geometry of the body or a discontinuity in it

shear wave — wave motion in which the particle motion is perpendicular to the direction of propagation

shear wave search unit (Y cut quartz search unit) — a straight beam search unit used for generating and detecting shear waves

signal-to-noise ratio — the ratio of the amplitude of an ultrasonic indication to the amplitude of the maximum background noise

skip distance — in angle beam examination, the distance along the test surface, from sound entry point to the point at which the sound returns to the same surface. It can be considered the top surface distance of a complete vee path of sound in the test material.

straight beam — a vibrating pulse wave train traveling normal to the test surface

suppression — see *reject (suppression)*

surface wave — see *Rayleigh wave*

sweep — the uniform and repeated movement of an electron beam across the CRT

swept gain — see *DAC*

testing, ultrasonic — a nondestructive method of examining materials by introducing ultrasonic waves into, through, or onto the surface of the article being examined and determining various attributes of the material from effects on the ultrasonic waves

test surface — that surface of a part through which the ultrasonic energy enters or leaves the part

through transmission technique — a test procedure in which the ultrasonic vibrations are emitted by one search unit and received by another at the opposite surface of the material examined

transducer — an electroacoustical device for converting electrical energy into acoustical energy and vice versa. See also *crystal.*

transverse wave — see *shear wave.*

transverse wave — wave motion in which the particle displacement at each point in a material is perpendicular to the direction of propagation (E 494)

true attenuation — that portion of the observed ultrasound energy loss which is intrinsic to the medium through which the ultrasound propagates. True attenuation losses may be attributed to the basic mechanisms of absorption and scattering. (E 664)

ultrasonic — pertaining to mechanical vibrations having a frequency greater than approximately 20,000 Hz

ultrasonic noise level — the large number of unresolved indications resulting from structure or possibly from numerous small discontinuities, or both (E 127)

ultrasonic spectroscopy — analysis of the frequency spectrum of an ultrasonic wave

vee path — the angle-beam path in materials starting at the search-unit examination surface, through the material to the reflecting surface, continuing to the examination surface in front of the search unit, and reflection back along the same path to the search unit. The path is usually shaped like the letter V.

vertical limit — the maximum readable level of vertical indications determined either by an electrical or a physical limit of an A-scan presentation

video presentation — display of the rectified, and usually filtered, r-f signal

water path — the distance from the transducer to the test surface in immersion or water column testing

wave front — a continuous surface drawn through the most forward points in a wave disturbance which have the same phase

wave train — a succession of ultrasonic waves arising from the same source, having the same characteristics, and propagating along the same path

wedge — in ultrasonic angle-beam examination by the contact method, a device used to direct ultrasonic energy into the material at an angle

wheel search unit — an ultrasonic device incorporating one or more piezoelectric elements mounted inside a liquid-filled flexible tire. The beam is coupled to the test surface through the rolling contact area of the tire.

wrap around — the display of misleading reflections from a previously transmitted pulse, caused by an excessively high pulse-repetition frequency

13. Infrared Examination (E 1213)

absorptance, α — the ratio of radiant flux absorbed by a surface to that incident upon it

apparent temperature — the temperature of an object as determined solely from the measured radiance, assuming an emissivity of unity

background radiation — all radiation received by the infrared sensing device that was not emitted by the specified area of the surface being examined

background, target — that portion of the background which is confined to the field of view

blackbody — an ideal thermal radiator (emissivity = 1.0) that emits and absorbs all of the available thermal radiation at a given temperature

blackbody equivalent temperature — the apparent temperature of an object as determined from the measured radiance and the assumption that it is an ideal blackbody with emissivity of 1.0

differential blackbody — an apparatus for establishing two parallel isothermal planar zones of different temperatures, and with effective emissivities of 1.0 (E 1213)

emissivity, ϵ — the ratio of the radiance of a body at a given temperature to the corresponding radiance of a blackbody at the same temperature

extended source — a source of infrared radiation whose image completely fills the field of view of a detector

NOTE 27 — The irradiance is independent of the distance from the source to the region of observation. In practice, sources that are not extended sources are considered to be point sources; see *point source.*

field of view (FOV) — the shape and angular dimensions of the cone or the pyramid which define the object space imaged by the system; for example, rectangular, 4 deg. wide by 3 deg. high

imaging line scanner — an apparatus that scans in a single dimension and is moved perpendicular to the scan direction to produce a two-dimensional thermogram of a scene

infrared imaging system — an apparatus that converts the two-dimensional spatial variations in infrared radiance from any object surface into a two-dimensional thermogram of the same scene, in which variations in radiance are displayed in gradations of gray tone or in color

infrared reflector — a material with a reflectance in the infrared region as close as possible to 1.00

infrared sensing device — one of a wide class of instruments used to display or record, or both, information related to the thermal radiation received from any object surfaces viewed by the instrument. The instrument varies in complexity from spot radiometers to two-dimensional real-time imaging systems.

infrared thermographer — the person qualified or trained to use infrared imaging radiometer

infrared thermography — see *thermography, infrared*

instantaneous field of view (IFOV) — for a scanning system, the angular dimensions in object space within which objects are imaged by an individual detector (unit = deg. or rad)

NOTE 28 — The IFOV is equivalent to the horizontal and vertical fields of view of the individual detector. For small detectors, the detector angular subtenses or projections, α and β, are defined by $\alpha = a/f$ and $\beta = b/f$ where a and b are the horizontal and vertical dimensions of the detector and f is the effective focal length of the optic. (IFOV may also be expressed as a solid angle in units of sr.)

irradiance, E — the radiant flux (power) per unit area incident on a given surface (unit = W/m^2)

limiting resolution — the highest spatial frequency of a target that an imaging sensor is able to resolve

line scanner — an apparatus that scans along a single line of a scene to provide a one-dimensional thermal profile of the scene

minimum detectable temperature difference (MDTD) — a measure of the compound ability of an infrared imaging system and an observer to detect a target of unknown location at one temperature against a large uniform background at another temperature when displayed on a monitor for a limited time

NOTE 29 — For a given target size, the MDTD is the minimum temperature difference between the target and its background at which the observer can detect the target. The standard target is a circle whose size is given by its angular subtense, and both target and background are isothermal blackbodies.

minimum resolvable temperature difference (MRTD) — a measure of the ability of an infrared imaging system and the human observer to recognize periodic bar targets on a display. The MRTD is the minimum temperature difference between a standard periodic test pattern (7:1 aspect ratio, 4 bars) and its blackbody background at which an observer can resolve the pattern as a four-bar pattern (see Fig. 4).

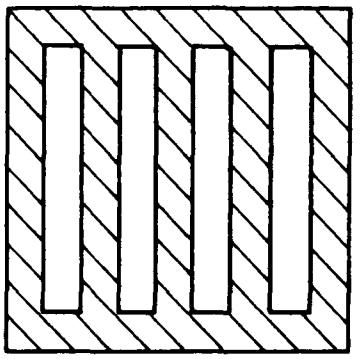


FIG. 4 SCHEMATIC DIAGRAM OF FOUR-BAR PATTERN WITH BACKGROUND, USED TO EVALUATE MINIMUM RESOLVABLE TEMPERATURE DIFFERENCE

modulation transfer function (MTF) — in infrared imaging systems, the modulus of a Fourier transform that describes the spatial distribution of the overall attenuation in amplitude of a thermal imaging system

NOTE 30 — MTF is a sensitive function of spatial frequency.

noise equivalent temperature difference (NETD) — the target-to-background temperature difference between a blackbody target and its blackbody background at which the signal-to-noise ratio of a thermal imaging system or scanner is unity

object plane resolution — the dimension in the object plane that corresponds to the product of a system's instantaneous field-of-view and a specified distance from the system to the object

point source — a source whose linear dimensions are very small compared with the distance from the source to the region of observation

NOTE 31 — The irradiance varies inversely with the square of the distance; a unique property of point sources.

radiance, L — the flux per unit projected area per unit solid angle leaving a source or, in general, any reference surface. If $d^2\Phi$ is the flux emitted into a solid angle $d\omega$ by a source element of projected area $dA \cos \theta$, the radiance is defined as:

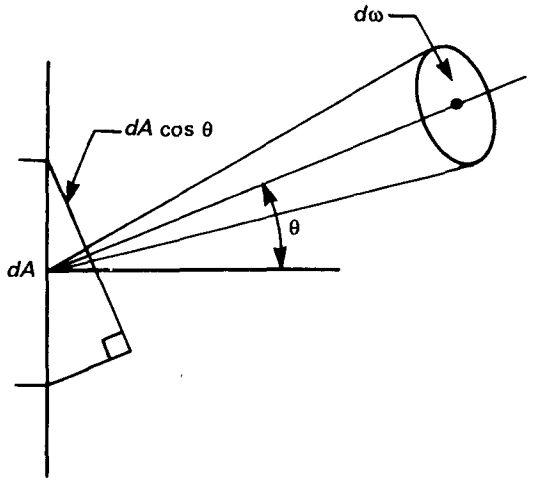


FIG. 5 SCHEMATIC REPRESENTATION OF RADIANCE

$$L = \frac{d^2\Phi}{d\omega \cdot dA \cos\theta}$$

where, as shown in Fig. 5, θ is the angle between the outward surface normal of the area element dA and the direction of observation (unit = $W/sr \cdot m^2$).

radiant exitance, M — the radiant flux per unit area leaving a surface. That is,

$$M = \frac{d\Phi}{dA}$$

where:

$d\Phi$ = flux leaving a surface element dA (unit = W/m^2).

NOTE 32 — In general, exitance includes emitted, transmitted, and reflected flux.

radiant flux; radiant power, ϕ_e — radiant energy per unit time (unit = W)

radiometer — an instrument for measuring the intensity of radiant energy. In infrared thermography, an apparatus that measures the average apparent temperature of the surface subtended by its field of view.

reflectance — the ratio of the radiant flux reflected from a surface to that incident upon it

reflected temperature — the temperature of the energy incident upon and reflected from the measurement surface of a specimen

spatial frequency — a measure of detail in terms of equivalent, uniformly spaced, cyclical patterns. In an object or image plane, it may be expressed in units of cycles per millimeter (cy/mm) or line pairs per millimeter (lp/mm). In an imaging system, it may be expressed in units of cycles per milliradian (cy/mrad) or line pairs per milliradian (lp/mrad).

thermal resolution — the smallest apparent temperature difference between two blackbodies that can be measured by an infrared sensing device

thermogram — a visual image which maps the apparent temperature pattern of an object or scene into a corresponding contrast or color pattern

thermography, infrared — the process of displaying variations of apparent temperature (variations of temperature or emissivity, or both) over the surface of an object or a scene by measuring variations in infrared radiance

NOTE 33 — In general, *passive thermography* refers to examination of an object or system during its normal operational mode, without the application of any additional energy source for the express purpose of generating a thermal gradient in the object or system; *active thermography* refers to the examination of an object upon intentional application of an external energy source. The energy source (active or passive) may be a source of heat, mechanical energy (vibration or fatigue testing), electrical current, or any other form of energy.

transmittance, τ — the ratio of the radiant flux transmitted through a body to that incident upon it

vibrothermography — a thermographic technique for examining an object in which temperature differences are produced by excitation

14. Optical Holography

amplitude hologram — a recording of the variation of light intensity caused by the interference between the reference beam and the object beam, as light or dark areas on the recording medium. The light and dark interference lines in the recording medium diffract laser light to produce the reconstruction.

beam ratio — the measured intensity of the reference beam divided by the measured intensity of the object beam in the plane of the recording medium

beamsplitter — an optical device for dividing a beam into two or more separate beams

coherence — a property of a beam of electromagnetic radiation in which the phase relationship between any two points across the beam or in time remains essentially constant (see *coherence length*)

coherence length — the path difference between the object beam and the reference beam at which interference

fringes reduce in contrast by a factor of $\sqrt{2}/2$ (0.707) from the point of maximum contrast. The coherence length is related to the width of the spectral line emitted from the laser: $L_c = c/\Delta v$, where c is the speed of light and Δv is the bandwidth of the spectral emission line.

exposure — the product of irradiance and time required to produce a suitable pattern on the recording medium

fringe — one of the light or dark bands produced by the interference of the light scattered by the real object and the virtual image of the object

holography (optical) — a technique for recording, and reconstructing, the amplitude and phase distributions of a wave disturbance; widely used as a method of three-dimensional optical image formation. The technique is accomplished by recording the pattern of interference between coherent light reflected from the object of interest (object beam), and light that comes directly from the same source (reference beam).

interference — the variation with distance or time of the amplitude of a wave which results from the superposition of two or more waves having the same, or nearly the same, frequency

monochromatic — a property of a beam of electromagnetic radiation in which all waves in the beam have the same wavelength

object beam — the portion of laser radiation which illuminates the test object surface, is scattered, and carries object information to the recording medium

object beam angle — the angle between a line from the center of the object to the center of the recording medium and the normal to the center of the recording medium

path length — the distance traveled by the laser radiation from the beam splitter to the recording medium

path length diffrerence — the difference in path length between the object beam and the reference beam

phase hologram — a recording of the variations in light intensity caused by the interference of the reference beam with the object beam as variations in the thickness or index of refraction of the recording medium. The variations in thickness or index refract coherent light to produce the reconstruction.

real image — a reproduction of an object by an optical system which gathers light from an object point and transforms it into a beam that converges toward another point

recording medium — a light-sensitive material which detects the interference between the object beam and the reference beam. Typical recording media used in holography are silver halide film, thermoplastic film, and electronic detectors such as video tubes and CCD arrays.

reference beam — laser radiation impinging directly upon the recording medium through optical components and which typically does not contain information about the test object. In some tests, the reference beam may be reflected or scattered from a portion of the object surface. In this case, any object information contained in the reference beam is cancelled in the object beam by the interference between the object beam and the reference beam.

reference beam angle — the angle formed between the centerline of the reference beam and the normal to the recording medium

speckle — the random interference pattern which results from the illumination of an optically rough surface with coherent radiation. In laser systems, it results in the granular effect which can be seen in a scattered beam.

virtual image — a reproduction of an object by an optical system which gathers light from an object point and transforms it into a beam that appears to diverge from another point

15. Visual and Optical Methods

accommodation, visual — adjustment of the eye, either the focus or the iris opening, to optimize its performance under the specific viewing conditions prevailing

ambient light — light not provided by the visual testing system

borescope — a flexible or rigid tube-like instrument used for a remote direct viewing visual aid. The instrument may consist of mirrors, prisms, lenses, optic-fibers a miniature CCD camera to transmit images to the viewing or recording medium

candela — a unit of luminous intensity (formerly candle). One candela is the luminous intensity in the perpendicular direction of a surface of 1/600 000 m2 of a blackbody radiator at the temperature of freezing platinum under a pressure of 101 325 Pa. One candela produces 1 lumen of luminous flux per steradian of a solid angle measured from the source

charge-coupled device (CCD), n — a light-detecting video device in which individual components are connected so that the electrical charge or signal at the output

of one component provides the input to the next

closure — process by which a person cognitively completes patterns or shapes that are incompletely perceived

contrast — the difference between the amount of light reflected or transmitted by an object and by the background within the field of view

depth of field — the range of distance over which an imaging system gives satisfactory definition when it is in the best focus for a specific distance

direct viewing — a view that is not redefined by optical or electronic means

feature extraction — characterization of objects in an image, usually with the goal of distinguishing those objects

fiber optics — method by which light is transmitted through thin transparent fibers

field angle — the included angle betwen those points on opposite sides of a light beam at which the luminous intenisity is 10% of the maximum value

filter — a processing component or function that excludes, passes, or amplifies a selected kind of signal or part of a signal

field coefficients — values which define a mask filter in image processing

glare — excessive brightness which interferes with clear vision, critical observation, and judgment

glossmeter — an instrument for measuring the ratio of the light regularly or specularly reflected from a surface to the total light reflected

illuminance — the density of luminous flux on a surface per unit area. Measured in the SI system by lux.

light — electromagnetic radiation in the spectral range detectable by the normal human eye (wavelengths of approximately 380 to 780 nm)

lumen — luminous flux emitted within one steradian by a point source having a spatially uniform luminous intensity of one candela. SI unit of luminous flux.

monochromator — a device for isolating monochromatic radiation from a beam of radiation which includes a broad range of wavelengths

reflection — the process by which the incident flux leaves a surface or medium from incident side, without a change in frequency, but may change polarity. Reflection is usually a combination of specular and diffuse reflection.

saturation — relative or comparative color characteristic resulting from a hue's dilution with white light

visibility — the quality or state of being perceived by the eye. In many outdoor applications, visibility is defined in terms of the distance at which an object can be reliably resolved from its surroundings. In outdoor applications it usually is defined in terms of contrast or size of a standard test object, observed under standardized viewing conditions, having the same threshold as the given object.

visual field — point or points in space that can be perceived when the head and eyes are kept fixed. The field may be monocular or binocular.

white light — light containing all wave lengths in the visible spectrum (in the range from 380 to 780 nm)

APPENDIX

(Nonmandatory Information)

X1. TERMS DEFINED IN THIS STANDARD

X1.1 The following is an alphabetized list of terms defined in this standard:

A-scan ... 12
absolute coil ... 6
absolute manometer ... 8
absolute measurements ... 6
absolute pressure ... 8
absolute readout ... 6
absolute system ... 6
absorbed dose ... 7
absorbed dose rate ... 7
absorptance, α ... 13
absorption ... 7, 8
accelerating potential ... 7
acceptable quality level ... 4
acceptance level ... 6
acceptance limits ... 6
acceptance standard ... 6
accommodation, visual ... 15
accumulation test ... 8
acoustic emission (AE) ... 5
acoustic emission channel ... 5
acoustic emission count (emission count) (N) ... 5
acoustic emission count rate (emission rate or count rate) (N) ... 5
acoustic emission event (emission event) ... 5
acoustic emission event energy ... 5
acoustic emission sensor ... 5
acoustic emission signal amplitude ... 5
acoustic emission signal (emission signal) ... 5
acoustic emission signal generator ... 5
acoustic emission signature (signature) ... 5
acoustic emission transducer ... 5
acoustic emission waveguide ... 5
activation ... 7, 11
acute radiation syndrome ... 7
adaptive location ... 5
AE activity ... 5
AE amplitude ... 5
AE rms ... 5
AE signal duration ... 13
AE signal end ... 13
AE signal risetime ... 13
AE signal start ... 13
alkali ion diode ... 8
alphanumeric ... 7
alpha particle ... 7
ambient light ... 15
ammeter shunt ... 10
amorphous selenium (α-Se) radiation detector array ... 7
amorphous silicon (α-Si) X-ray detector ... 4
ampere turns ... 10
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amplitude distortion ... 6
amplitude hologram ... 14
amplitude response ... 6
analog image ... 7
analog to digital converter (a/d) ... 7
angle beam ... 12
angstrom unit (A) ... 9
annular coil clearance ... 6
annular coils ... 6
anode ... 7
anode current ... 7
aperture ... 7
aperture leak ... 8
apparent attenuation ... 12
apparent temperature ... 13
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area of interest ... 7
array ... 5
array processor ... 7
arrival time interval (Δ_m) ... 5
artifact ... 7
artificial discontinuity ... 6
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atmospheric pressure ... 8
atomic mass unit (amu) ... 8
attenuation ... 5, 12
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attenuation cross section ... 11
attenuator ... 12
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autoradiograph ... 7
average signal level ... 5
B-scan presentation ... 12
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back pressure test ... 8
back scattered radiation ... 7
back surface ... 12
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backing space ... 8
backing space technique ... 8
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ballast ... 8
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barn ... 11
base line ... 12
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Bayard-Alpert ionization gage ... 8
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bell jar testing 8
betatron 7
bipolar field 10
blackbody 13
blackbody equivalent temperature 13
black light 9, 10
black light filter 9, 10
bleedout 9
blocking or masking 7
blooming 7
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bubble immersion test 8
bubbler 12
bucking coils 6
burst emission 5
C-scan 12
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calibration, instrument 4
candela 15
carrier 9
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characteristic curve 7
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closure 15
clusec 8
coercive force 10
coherence 14
coherence length 14
coil, absolute 6
coil method 10
coil, reference 6
coil size 6
coil spacing 6
coil technique 10
coil, test 6
cold-cathode ionization gage 8
collimator 7, 12
comparative measurements 6
comparative readout 6
comparative system 6
comparator coils 6
composite viewing 7
compressional wave 12
compton scatter radiation 7
computed location 5
computed radiology (photo stimulated luminescence method) 7
concentration ratio 8
conditioning agent 10
conductance 8
conductivity 6
constant potential 7
contact head 10
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contact testing 12
contaminant 9
continuous emission 5
continuous method 10
continuous wave 12
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contrast agent 11
contrast sensitivity 7
contrast stretch 7
control echo 12
conversion screen 11
core (of an electromagnetic inspection circuit) 10
corner effect 12
count, acoustic emission (emission count) (N) 5
count, event (Ne) 5
count, ring-down 5
count rate, acoustic emission (emission rate or count rate) (N) 5
couplant 5, 12
coupling 6
cracking 8
critical angle 12
cross section 11
cross talk 12
crystal (see transducer) 12
cumulative (acoustic emission) amplitude distribution F(V) 5
cumulative (acoustic emission) threshold crossing distribution Ft/(V) 5
Curie point 10
current flow method 10
current induction method 10
cut-off level 6
DAC 12
damping, search unit 12
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dB_{AE} 5
dB control 12
dead time, instrumentation 5
dead zone 12
defect 4
defect resolution 6
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delayed sweep 12
demagnetization 10
densitometer 7
density (film) 7
density comparison strip 7
depth of field 15
depth of penetration 6
detergent remover 9
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developer, dry powder 9
developer, liquid film 9
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developer, soluble 9
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differential (acoustic emission) threshold crossing distribution [ft(V)] ... 5
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differential coils ... 6
differential leak detector ... 8
differential measurements ... 6
differential Pirani gage ... 8
differential readout ... 6
differential signal ... 6
differential system ... 6
diffuse indications ... 10
diffusion ... 8
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digital image acquisition system ... 7
digital image enhancement ... 7
digital image processing system ... 7
digitize (for radiology) ... 7
direct contact magnetization ... 10
direct exposure imaging ... 11
direct viewing ... 15
discharge pressure ... 8
discharge tube leak indicator ... 8
discontinuity ... 4
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distance amplitude compensation ... 12
distance amplitude response curve ... 12
distance linearity range ... 12
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distribution, threshold crossing, cumulative (acoustic emission) Ft(v) ... 5
distribution, differential (acoustic emission) amplitude f(V) ... 5
distribution, differential (acoustic emission) threshold crossing ft(V) ... 5
distribution logarithmic (acoustic emission) amplitude g(V) ... 5
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eddy current testing ... 6
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effective velocity ... 5
electrical center ... 6
electromagnet ... 10
electromagnetic testing ... 6
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nonrelevant indication ... 4
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noncondensable gas ... 8
nonferromagnetic material ... 6
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ARTICLE 31
ALTERNATING CURRENT FIELD MEASUREMENT STANDARDS

STANDARD PRACTICE FOR EXAMINATION OF WELDS USING THE ALTERNATING CURRENT FIELD MEASUREMENT TECHNIQUE

A06

SE-2261

(Identical with ASTM Specification E 2261-03.)

1. Scope

1.1 This practice describes procedures to be followed during alternating current field measurement examination of welds for baseline and service-induced surface breaking discontinuities.

1.2 This practice is intended for use on welds in any metallic material.

1.3 This practice does not establish weld acceptance criteria.

1.4 The values stated in either inch-pound units or SI units are to be regarded separately as standard. The values stated in each system might not be exact equivalents; therefore, each system shall be used independently of the other.

1.5 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Agencies Performing Nondestructive Testing

E 1316 Terminology for Nondestructive Examinations

2.2 *ASNT Standard:*

SNT-TC-1A Personnel Qualification in Nondestructive Testing

ANSI/ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

3. Terminology

3.1 General definitions of terms used in this practice can be found in Terminology E 1316, Section A, Common NDT terms, and Section C, Electromagnetic testing.

3.2 *Definitions:*

3.2.1 *exciter* — a device that generates a time varying electromagnetic field, usually a coil energized with alternating current (AC); also known as a transmitter.

3.2.2 *detector* — one or more coils or elements used to sense or measure a magnetic field; also known as a receiver.

3.2.3 *uniform field* — as applied to nondestructive testing, the area of uniform magnetic field over the surface of the material under examination produced by a parallel induced alternating current, which has been passed through the weld and is observable beyond the direct coupling of the exciting coil. The field is uniform on the surface but the strength decays exponentially with depth.

3.2.4 *alternating current field measurement* — a nondestructive examination technique that measures changes in an applied AC uniform magnetic field to detect and characterize discontinuities.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *alternating current field measurement system* — the electronic instrumentation, software, probes, and all associated components and cables required for performing weld examination using the alternating current field measurement technique.

3.3.2 *operational standardization block* — a reference standard with specified artificial slots, used to confirm the operational parameters and to indicate discontinuity detection sensitivity.

3.3.3 B_x — the x component of the magnetic field, parallel to the weld toe, the magnitude of which is proportional to the current density set up by the electric field.

3.3.4 B_z — the z component of the magnetic field normal to the weld toe, the magnitude of which is proportional to the curvature of the current in the x-y plane.

3.3.5 *X-Y Plot* — an X-Y graph with two orthogonal components of magnetic field plotted against each other.

3.3.6 *time base plots* — these plot the relationship between B_x or B_z values with time.

3.3.7 *surface plot* — for use with array probes. These plot one component of magnetic field over an area, typically as a color contour plot or 3-D wire frame plot.

3.3.8 *data sample rate* — the rate at which data is digitized for display and recording, in data points per second.

4. Summary of Practices

4.1 In a basic alternating current field measurement system, a small probe is moved along the toe of a weld. The probe contains an exciter coil, which induces an AC magnetic field in the material surface aligned to the direction of the weld. This, in turn, causes uniform alternating current to flow across the weld, orthogonal to the toe. The depth of penetration of this current varies with material type and frequency but is typically 0.004 in. [0.1 mm] deep in magnetic materials and 0.08–0.3 in. [2–7 mm] deep in non-ferrous materials. Any surface breaking

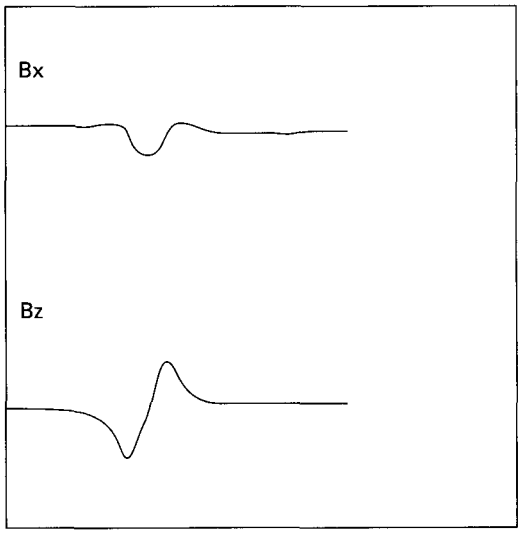

FIG. 1 TYPICAL B_x AND B_z TRACES AS A PROBE PASSES OVER A CRACK

discontinuities within 0.4 in. [10 mm] of either side of the scan line at this location will interrupt or disturb the flow of the otherwise uniform electromagnetic field. Measurement of the absolute quantities of the two major components of the surface magnetic fields (B_x and B_z) determines the severity of the disturbance (see Fig. 1) and thus the severity of the discontinuity. Discontinuity sizes, such as crack length and depth, can be predicted from key points selected from the B_x and B_z traces along with the standardization data and instrument settings from each individual probe. This discontinuity sizing can be performed automatically using system software.

4.2 Standardization data and instrument settings for each individual probe are determined at the factory and stored in a computer file, which is loaded at the start of the examination. System sensitivity is verified using an operation standardization block. System sensitivity is checked and recorded prior to and at regular intervals during the examination. Note that when a unidirectional input current is used, any decay in strength of the input field with probe lift-off or thin coating is relatively small so that variations of output signal (as may be associated with a discontinuity) are reduced. If a thick coating, that is, greater than 0.04 in. [1 mm] is present then the discontinuity size prediction must compensate for the coating thickness. This can be accomplished using discontinuity-sizing tables in the system software. Using the wrong coating thickness would have a negative effect on depth sizing accuracy if the discrepancy was 0.04 in. [1 mm] or more. As the current flow is arranged normal to the weld toe there is no perturbation in that direction so that no indication occurs at the interface due to changes in

permeability. Data is recorded in a manner that allows archiving and subsequent recall for each weld location. Evaluation of examination results may be conducted at the time of examination or at a later date. The examiner generates an examination report detailing complete results of the examination.

5. Significance and Use

5.1 The purpose of the alternating current field measurement method is to evaluate welds in the area of the toe for surface breaking discontinuities such as fatigue cracks. The examination results may then be used by qualified organizations to assess weld service life or other engineering characteristics (beyond the scope of this practice).

5.2 *Comparison with Conventional Eddy Current Examination.* Conventional eddy current coils are typically configured to sense the field from the weld in the immediate vicinity of the emitting element, whereas alternating current field measurement probes are typically designed to sense the magnetic field from the weld distant from the exciter.

6. Basis of Application

6.1 *Personnel Qualification*

6.1.1 If specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189 or SNT-TC-1A or a similar document and certified by the employer or certifying agent, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Evaluation Agencies.* If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543, with reference to sections on electromagnetic examination. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

7. Job Scope and Requirements

7.1 The following items may require agreement by the examining party and their client and should be specified in the purchase document or elsewhere:

7.1.1 Location and type of welded component to be examined, design specifications, degradation history, previous nondestructive examination results, maintenance history, process conditions, and specific types of discontinuities that are required to be detected, if known.

7.1.2 The maximum window of opportunity for work. (Detection of small discontinuities may require a slower probe scan speed, which will affect productivity.)

7.1.3 Size, material grade and type, and configuration of welds to be examined.

7.1.4 A weld numbering or identification system.

7.1.5 Extent of examination, for example: complete or partial coverage, which welds and to what length, whether straight sections only and the minimum surface curvature.

7.1.6 Means of access to welds, and areas where access may be restricted.

7.1.7 Type of alternating current field measurement instrument and probe; and description of operations standardization block used, including such details as dimensions and material.

7.1.8 Required operator qualifications and certification.

7.1.9 Required weld cleanliness.

7.1.10 Environmental conditions, equipment and preparations that are the responsibility of the client; common sources of noise that may interfere with the examination.

7.1.11 Complementary methods or techniques may be used to obtain additional information.

7.1.12 Acceptance criteria to be used in evaluating discontinuities.

7.1.13 Disposition of examination records and reference standards.

7.1.14 Format and outline contents of the examination report.

8. Interferences

8.1 This section describes items and conditions, which may compromise the alternating current field measurement technique.

8.2 *Material Properties:*

8.2.1 Although there are permeability differences in a ferromagnetic material between weld metal, heat affected zone material and parent plate, the probe is normally scanned along a weld toe and so passes along a line of relatively constant permeability. If a probe is scanned across a weld then the permeability changes may produce indications, which could be similar to those from

a discontinuity. Differentiation between a transverse discontinuity signal and the weld signal can be achieved by taking further scans parallel to the discontinuity. The signal from a discontinuity will die away quickly. If there is no significant change in indication amplitude at 0.8 in. [20 mm] distance from the weld then the indication is likely due to the permeability changes in the weld.

8.3 *Magnetic State*

8.3.1 *Demagnetization.* It must be ensured that the surface being examined is in the non-magnetized state. Therefore the procedure followed with any previous magnetic technique deployed must include demagnetization of the surface. This is because areas of remnant magnetization, particularly where the leg of a magnetic particle examination yoke was sited, can produce loops in the X-Y plot, which may sometimes be confused with a discontinuity indication.

8.3.2 *Grinding Marks.* Magnetic permeability can also be affected by surface treatments such as grinding. These can cause localized areas of altered permeability across the line of scan direction. The extent and pressure of any grinding marks should always be reported by the probe operator, since these can give rise to strong indications in both B_x and B_z, which may be confused with a discontinuity indication. If a discontinuity is suspected in a region of grinding, further scans should be taken parallel but away from the weld toe. The indication from a linear discontinuity will die away quickly away from the location of the discontinuity so that the scan away from the weld toe will be flatter. If there is no significant change in indication amplitude at 0.80 in. [20 mm] distance from the weld then the indication is likely due to the effect of the grinding.

8.4 Residual stress, with accompanying permeability variations, may be present with similar, but much smaller, effects to grinding.

8.5 *Seam Welds*

8.5.1 Seam welds running across the line of scanning also produce strong indications in the B_x and B_z, which can sometimes be confused, with a discontinuity indication. The same procedure is used as for grinding marks with further scans being taken away from the affected area. If the indication remains constant then it will not have been produced by a linear discontinuity.

8.6 *Ferromagnetic and Conductive Objects*

8.6.1 Problems may arise because of objects near the weld that are ferromagnetic or conductive which may reduce the sensitivity and accuracy of discontinuity characterization when they are in the immediate vicinity of the weld.

8.7 *Neighboring Welds*

8.7.1 In areas where welds cross each other, there are indications, which may be mistaken for discontinuities. (See 8.5.)

8.8 *Weld Geometry*

8.8.1 When a probe scans into a tight angle between two surfaces the B_x indication value will increase with little change in the B_z. This will cause the X-Y plot to rise.

8.9 *Crack Geometry Effects*

8.9.1 *A discontinuity at an angle to the scan* — a discontinuity at an angle to the scan will reduce either the peak or the trough of the B_z as the sensor probe only passes through the edge of one end of the discontinuity. This produces an un-equal sided X-Y plot. Additional scans may be made along the weld or parent plate to determine the position of the other end of the discontinuity.

8.9.2 *A discontinuity at an angle to the surface* — the effect of a discontinuity at a non-vertical angle to the probe is generally to reduce the value of the B_z signal. The value of the B_x signal will not be reduced. This has the effect of reducing the width of the X-Y plot.

8.9.3 *Line contact or multiple discontinuities* — when contacts occur across a discontinuity then minor loops occur within the main X-Y plot loop produced by the discontinuity. If more than one discontinuity occurs in the scan then there will be a number of loops returning to the background.

8.9.4 *Transverse discontinuities* — if a transverse discontinuity occurs during the scan for longitudinal discontinuities then the B_x will rise instead of falling and the B_z signal will remain the same as for a short longitudinal discontinuity. The X-Y plot will then go upwards instead of down.

8.9.5 *Alternating current field measurement end effect* — the field from the standard weld probe is able to propagate around the end of a weld and this can result in sloping changes in the B_x and B_z traces. A discontinuity indication may be obscured or distorted if the discontinuity or any active probe element is close to the weld end. The distance over which this effect occurs depends on probe type, but can be up to 2 in. [50 mm] for large probes. Smaller probes should be used in these situations as they have less susceptibility to edge effect.

8.10 *Instrumentation*

8.10.1 The operator should be aware of indicators of noise, saturation or signal distortion particular to the instrument being used. Special consideration should be given to the following concerns:

8.10.1.1 Frequency of operation should be chosen to maximize discontinuity sensitivity whilst maintaining acceptable noise levels.

8.10.1.2 Saturation of electronic components is a potential problem in alternating current field measurement because signal amplitude can increase rapidly as a probe is scanned into tight angle geometry. This could cause the B_x indication to rise above the top of the range of the A/D converter in the instrument. Data acquired under saturation conditions is not acceptable.

8.10.2 *Instrument-induced Phase Offset.* The measurements of magnetic field are at a chosen and fixed phase so that unlike during eddy current examination the phase angle does not need to be considered. The phase is selected at manufacture of the probes and is stored in the probe file and is automatically configured by the instrument.

8.11 *Coating Thickness*

8.11.1 If a thick coating, that is, greater than 0.04 in. [1 mm] is present then the discontinuity size prediction must compensate for the coating thickness. This can be accomplished using discontinuity tables in the system software. Using the wrong coating thickness would reduce the depth sizing accuracy if the discrepancy was 0.04 in. [1 mm] or more.

9. Alternating Current Field Measurement System

9.1 *Instrumentation*

9.1.1 The electronic instrumentation shall be capable of energizing the exciter at one or more frequencies appropriate to the weld material. The apparatus shall be capable of measuring the B_x and B_z magnetic field amplitudes at each frequency. The instrument will be supplied with a portable personal computer (PC) that has sufficient system capabilities to support the alternating current field measurement software, which will be suitable for the instrument and probes in use and the examination requirements. The software provides control of the instrumentation including set-up, data acquisition, data display, data analysis and data storage. The software provides algorithms for sizing the discontinuities (see 11.2.2). The software runs on the PC and, on start up, all communications between the PC and the instrument are automatically checked. When the software starts up it automatically sets up the instrument connected in the correct mode for alternating current field measurement examination. The set up data for each probe is stored on the PC and is transmitted to the instrument whenever a probe is selected or changed (see 11.2.2). Once the instrumentation is set up for a particular probe, the software can be used to start and stop data acquisition. During data acquisition at least two presentations of the data are presented on the PC screen in real time (see 4.1). Data from the probe is displayed against time and also as an X-Y plot. Once collected the data can be further analyzed offline using the software to allow, for example, discontinuity sizing (see 11.2.2) or annotation for transfer to examination reports. The software also provides facilities for all data collected to be electronically stored for subsequent review or reanalysis, printing or archiving.

9.2 *Driving Mechanism*

9.2.1 When a mechanized system is in operation, a mechanical means of scanning the probe, or probes in the form of an array, along a weld or surface area at approximately constant speed may be used.

9.3 *Probes*

9.3.1 The probes selected should be appropriate for the form of examination to be carried out dependent on length of weld, geometry, size of detectable discontinuity and surface temperature.

9.3.1.1 *Standard weld probe* — commonly used for weld examination whenever possible as it has its coils positioned ideally for discontinuity sizing.

9.3.1.2 *Tight access probe* — designed specifically for occasions where the area under examination is not accessible with the standard weld probe. It is not as accurate as the weld probe for sizing in open geometries such as butt welds.

9.3.1.3 *Grind repair probe* — designed for the examination of deep repair grinds. It has the same basic geometry as a standard probe but is more susceptible to produce indications from vertical probe movement.

9.3.1.4 *Mini-probe* — designed for restricted access areas such as cut outs and cruciforms and has a reduced edge effect. It may be limited to shallow discontinuities only and is more sensitive to lift off. This probe may be in the form of a straight entry or 90 deg.

9.3.1.5 *Micro-probe* — designed for high-sensitivity discontinuity detection in restricted access areas and has the same limitations as a mini-probe. This probe may be in the form of a straight entry or 90 deg.

9.3.1.6 *Array probe* — made up of a number of elements; each element is sensitive to a discrete section of the weld width. The elements may be oriented with their axes aligned longitudinally or transversely with respect to the weld toe. The array probe is generally used either for scanning a weld cap in one pass or for covering a section of plate.

9.3.1.7 *Edge effect probe* — designed to reduce the edge effect when carrying out examination only near the ends of welds. (A mini probe may also be used for the same examination.)

9.4 *Data Displays*

9.4.1 The data display should include B_x and B_z indications as well as an X-Y plot.

9.4.2 When multi-element array probes are being used, the facility to produce color contour maps or 3D-wire frame plots representing peaks and troughs should be available.

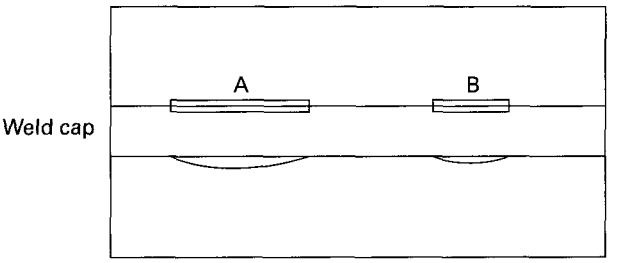

FIG. 2 FLAT PLATE SAMPLE SERIAL NUMBER XXX SHOWING SIZE AND LOCATION OF SEMI-ELLIPTICAL SLOTS (PLAN VIEW AND SIDE VIEW. NOT TO SCALE.)

10. Alternating Current Field Measurement Weld Standards

10.1 Weld standards are not required when the technique is to be used to examine carbon steel welds.

10.2 *Materials Other Than Carbon Steel*

10.2.1 If the technique is to be used on other material then it may be necessary to standardize the probes on this material as many of the probes are only standardized by the equipment manufacturer for use with carbon steel. If this is not done then the sizes of the indications may be too small (so that small discontinuities may be missed) or too large (so that spurious indications may be called), or the B_x indication may saturate making the examination invalid. This standardization is done using a slot of reasonable size located at a weld toe of a representative sample. The gain settings are altered until a loop of reasonable size is produced in the X-Y plot while background noise indications are kept low. When the technique is to be used to size the depths of discontinuities detected in material other than carbon steel, then a standardization block should be manufactured from the material with at least three elliptical slots of differing depth. This should be used to produce a standardization curve of actual depths versus the predicted depths from the carbon steel software model.

10.3 Reference weld standards for materials other than steel shall not be used for discontinuity characterization unless the artificial discontinuities can be demonstrated to be similar to the discontinuities detected.

10.4 *Typical Artificial Discontinuities in Discontinuity Characterization Standards*

10.4.1 Elliptical slots-slots of different depths typically 0.08 in. and 0.2 in. [2 mm and 5 mm] deep as used in the operation standardization block may be used as a quality check and also for the production of new probe files. If the material is other than carbon steel then these slots may be used in the production of standardization curves. These slots should be less than 0.02 in. [0.5 mm] wide.

10.5 *Reference Standards*

10.5.1 Discontinuity depths are specified by giving the deepest point of the discontinuity. Discontinuity depths shall be measured and accurate to ±0.010 in. [±0.25 mm] of the depth specified. All other discontinuity dimensions (such as length) shall be accurate to within ±0.040 in. [±1.00 mm] of the dimension specified.

10.6 *Artificial Slots for the Operation Standardization Block*

10.6.1 The operation standardization block has specific artificial discontinuities. It is used to check that the instrument and probe combination is functioning correctly. Unless otherwise specified by the client, the artificial discontinuities for the operation standardization block are as follows:

10.6.1.1 Elliptical slots-two elliptical slots placed in the weld toe with dimensions 2.0 in. × 0.2 in. [50mm × 5mm] and 0.8 in. × 0.08 in. [20 mm × 2 mm] (Fig. 2, discontinuities A and B.)

10.7 *Manufacture and Care of the Operation Standardization Blocks and Non-carbon Steel Weld Standards*

10.7.1 *Drawings.* For each operation standardization block and standard, there shall be a drawing that includes the as-built measured slot dimensions, material type and grade, and the serial number of the actual operation standardization block or weld standard.

10.7.2 *Serial Number.* Each operation standardization block or weld standard shall be identified with a unique serial number and stored so that it can be obtained and used for reference when required.

10.7.3 *Slot Spacing.* Artificial slots should be positioned longitudinally to avoid overlapping of indications and interference from end effects.

10.7.4 Proper machining practices shall be used to avoid excessive cold-working, over-heating, and undue stress and permeability variations.

10.7.5 Blocks should be stored and shipped so as to prevent mechanical damage.

11. Equipment Performance Check

11.1 *Instrument Settings:*

11.1.1 *Operating Frequency.* Using the appropriate operation standardization block the procedure in 11.2.2 below is intended to help the user select an operating frequency. Demonstrably equivalent methods may be used. The standard operating frequency is 5 kHz, but depending on which equipment is being used then higher or lower operating frequencies are available. A higher operating frequency will give better sensitivity on good surfaces. If the system available is not capable of operating at the frequency described by this practice, the inspector shall declare to the client that conditions of reduced sensitivity may exist.

11.2 *Test System Check and Procedure*

11.2.1 The test system shall consist of an alternating current field measurement instrument, the PC, the probe and the operation standardization block.

11.2.2 The equipment performance check will be performed using the appropriate operation standardization block containing slots of 2.0 in. × 0.20 in. [50 mm × 5 mm] and 0.8 in. × 0.08 in. [20 mm × 2 mm]. The probe is placed at the toe of the weld with the nose of the probe parallel to the longitudinal direction of the weld. The probe is then scanned across the operation standardization block and over the 2.0 in. × 0.2 in. [50 mm × 5 mm] slot producing a standardized data plot. Discontinuity indications are created when (1) the background level B_x value is reduced and then returns to the nominal background level, Fig. 1, and this is associated with (2) a peak or positive (+ve) indication followed by a trough or negative (−ve) indication (or a trough followed by a peak, depending on direction of scan) in the B_z values. The resultant effect of the changes in B_x and B_z is a downward loop in the X-Y plot, Fig. 3. The presence of a discontinuity is confirmed when all three of these indications are present, that is, the B_x, the B_z and a downward loop in the X-Y plot. The loop should fill approximately 50% of the height and 175% of the width of the X-Y plot. The scanning speed or data sampling rate can then be adjusted if necessary, depending on the length and complexity of weld to be examined.

11.2.2.1 Once the presence of the discontinuity has been confirmed by the B_x and B_z indications the discontinuity should be sized.

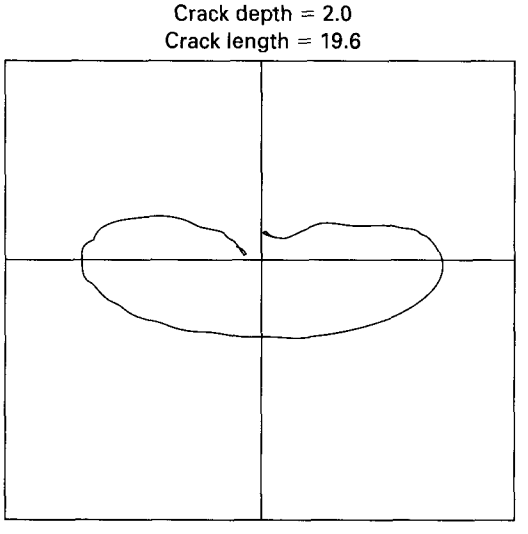

FIG. 3 TYPICAL X-Y PLOT PRODUCED BY PLOTTING THE B_x AND B_z TOGETHER

11.2.2.2 Discontinuity sizing is performed in the examination software and uses look-up tables of expected responses versus discontinuity sizes. These tables can be based upon mathematical models that simulate the current flow around the discontinuities and the resultant change in surface magnetic field by running the model for a large number of discrete discontinuities with various lengths and depths. The operator enters background and minimum values of B_x along with the B_z length and any coating thickness to allow the software to predict discontinuity length and depth. The results from the model must be checked against a library of real discontinuities to confirm the validity of the sizing tables.

11.2.2.3 If these values differ from those expected from the operation standardization block then the instrument and probe settings should be checked. Each probe should have a unique probe file, the validity of which has been checked against the discontinuity sizing tables. The instrument settings can be checked using the software package.

11.2.3 Each combination of alternating current field measurement unit and probe to be used during the examination should be used with the operations standardization block. Results obtained with these combinations should be the same as the slots in the block. If they differ by more than 10%, check that the correct probe files and gain have been used. If the correct probe files and gain have been used then there is a fault with the system, which will have to be determined. Do not use for examination unless standardization validity is confirmed within 10%.

11.3 *Frequency of Systems Check*

11.3.1 The system should be checked with all of the probes to be used during the examination prior to examining the first weld.

11.3.2 System performance should be checked at least every four hours with the probe in use or at the end of the examination being performed. If the discontinuity responses from the operation standardization block have changed by 10%, the welds examined since the last operations standardization block check shall be re-examined after following the procedure in 11.2.3.

12. Examination Procedure

12.1 If necessary, clean the weld surface to remove obstructions and heavy ferromagnetic or conductive debris.

12.2 Following the guidelines in 9.3, select a suitable probe for the examination task, then, using the installed software, select a data file and a probe file.

12.2.1 The probe is placed at the toe of the weld with the nose of the probe parallel to the longitudinal direction of the weld.

12.2.2 The probe is then scanned along the weld. Discontinuity indications are created when the following three points are indicated:

12.2.2.1 The background level B_x value is reduced and then returns to the nominal background level, Fig. 1.

12.2.2.2 This is associated with a peak, or positive (+ve) indication followed by a trough, or negative (−ve) indication (or a trough followed by a peak, depending on direction of scan) in the B_z values, Fig. 1.

12.2.2.3 The resultant effect of the changes in B_x and B_z is a downward loop in the X-Y plot, Fig. 3.

12.2.3 The presence of a discontinuity is confirmed when all three of these indications are present, that is, the B_x, the B_z and a downward loop in the X-Y plot. The scanning speed or data sampling rate can be adjusted if necessary, depending on the length and complexity of weld to be examined.

12.3 *Compensation for Material Differences*

12.3.1 To compensate for the small differences in readings caused by variations in permeability, conductivity or geometry for a given material, the data may be centered on the display area.

12.4 *Compensation for Ferromagnetic or Conductive Objects*

12.4.1 Techniques that may improve alternating current field measurement results near interfering ferromagnetic or conductive objects include:

12.4.1.1 Comparison of baseline or previous examination data with the current examination data.

12.4.1.2 The use of special probe coil configurations.

12.4.1.3 Use of higher or lower frequency probes may suppress non-relevant indications.

12.4.1.4 The use of a complementary method or technique.

12.5 Size and record all discontinuity indications as described in Section 14.

12.6 Note areas of limited sensitivity, using indications from the operation standardization block as an indicator of discontinuity detectability.

12.7 Using a discontinuity characterization standard, evaluate relevant indications in accordance with acceptance criteria specified by the client, if applicable.

12.8 If desired, examine selected areas using an appropriate complementary method or technique to obtain more information, adjusting results where appropriate.

12.9 Compile and present a report to the client.

13. Examination Considerations

13.1 *Scanning Speed*

13.1.1 The recommended scanning speed is 1 in. [25 mm]/second using the appropriate data sampling rate. This will produce a regular scan on the PC screen. If short welds are to be examined then a faster data sampling rate should be used. If long welds are to be examined and the whole weld needs to be seen on the PC screen then a slower data-sampling rate should be used. The weld length and speed of scanning will govern the data-sampling rate selected. With the introduction of faster software it is possible to select respective data sampling rates to produce faster scanning rates.

13.1.2 Acquire and record data from the operation standardization block at the selected examination speed.

13.1.3 Acquire and record data from the welds to be examined. Maintain as uniform a probe speed as possible throughout the examination to produce repeatable indications.

13.2 *Width of Scan*

13.2.1 Unless otherwise stated, a non-array probe has a scan width of 0.80 in. [20 mm]. Both toes of the weld should be scanned and if the cap is wider than 0.80 in. [20 mm] an extra scan should be performed along the cap. If the weld cap is narrow, that is, 0.40 in. [10 mm] a central scan only could be performed.

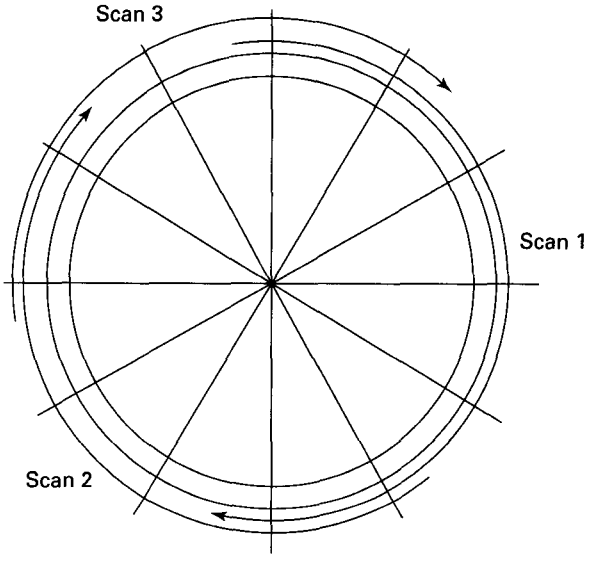

FIG. 4 SCANNING PATTERN FOR A CIRCUMFERENTIAL WELD

13.3 *Continuous Cracking*

13.3.1 Prior to the scanning of a weld, checks should be made that the discontinuity is not continuous by scanning the probe from 2 in. [50 mm] away from the weld towards the toe. If a discontinuity is present the Bx indication on the computer screen will dip as the probe approaches the weld toe. If this form of indication occurs then this procedure shall be repeated at intervals along the toe of the weld.

13.4 *Scanning Direction*

13.4.1 The probe should always be scanned parallel to the weld toe and this will give recognizable indications from longitudinal discontinuities in the weld area. Scanning in this direction will also give recognizable indications from transverse discontinuities and discontinuities inclined to the toe of the weld.

13.5 *Circumferential Welds*

13.5.1 The scanning pattern for a circumferential weld is shown in Fig. 4. Overlapping scans are required to ensure no discontinuities are missed if they occur at the end of a scan. The number of overlapping scans will vary depending on the component diameter. The overlap should be between 1 in. [25 mm] and 2 in. [50 mm] depending on the diameter of the tube or pipe. All detection shall be complete before any sizing operation is performed. Remember to check for continuous discontinuities before scanning.

13.6 *Linear Welds*

13.6.1 The scanning pattern is similar for that of circumferential welds except that an edge effect may occur at the end of the weld or if the weld ends at a buttress. In the case of the end of the weld an edge-effect probe should be used but for the buttress a mini- or micro-probe should be used. These probes can also be used as an alternative to the edge-effect probe. The standard weld probe should be used for sizing if at all possible.

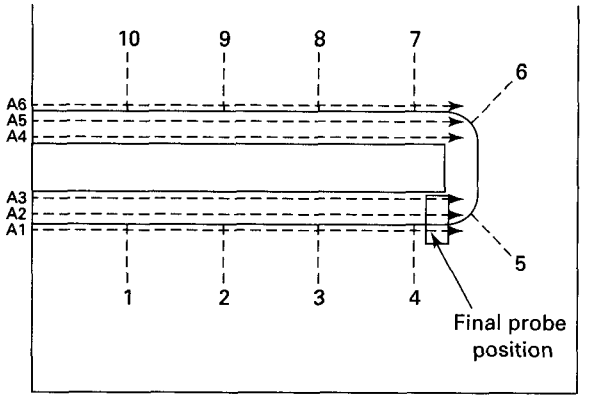

FIG. 5 SCANNING PATTERN FOR AN APPROACH TO AN ATTACHMENT

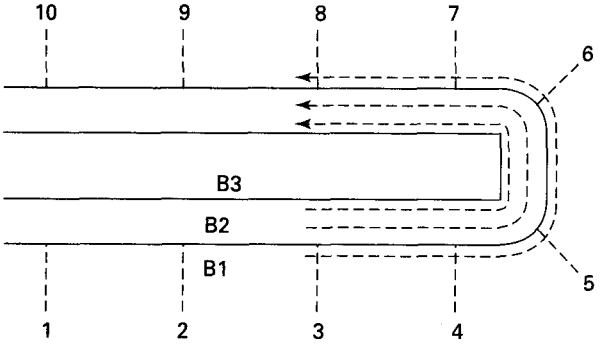

FIG. 6 SCANNING PATTERN FOR THE END OF AN ATTACHMENT

13.7 *Attachments, Corners, and Cutouts*

13.7.1 The scanning patterns for the attachment welds and gussets are shown in Fig. 5, Fig. 6, and Fig. 7 where lines A1-A6, B1-B3, and C1 and 2 are the probe scan lines and positions 1-10 are the incremental positions along the weld length. The corners are difficult to scan and the micro- or mini-probes should be used where possible.

13.8 *Cutouts and Cruciform Geometries*

13.8.1 The examination of this geometry is difficult due to the access problems; the scanning patterns and identification of the areas are shown in Fig. 8, Fig. 9, Fig. 10, and Fig. 11. The 90 deg mini- or micro-probe is essential for examining the cutout areas.

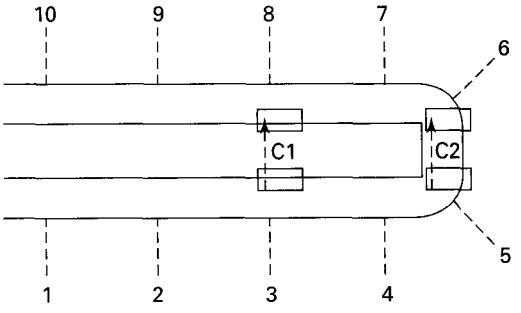

FIG. 7 SCANNING PATTERN ACROSS AN ATTACHMENT (CRACK IN THE TOE END)

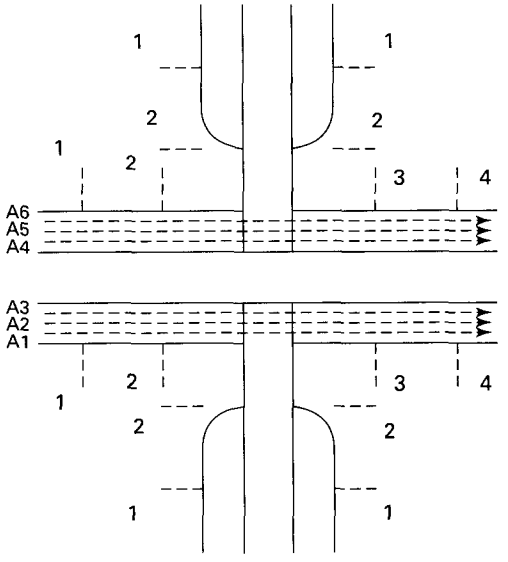

FIG. 8 SCANS OF THE MAIN WELD

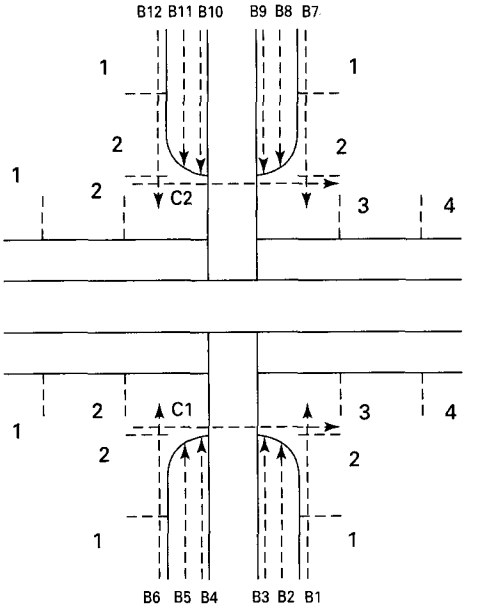

FIG. 9 SCANS OF THE HORIZONTAL WELD INTO A CUT OUT

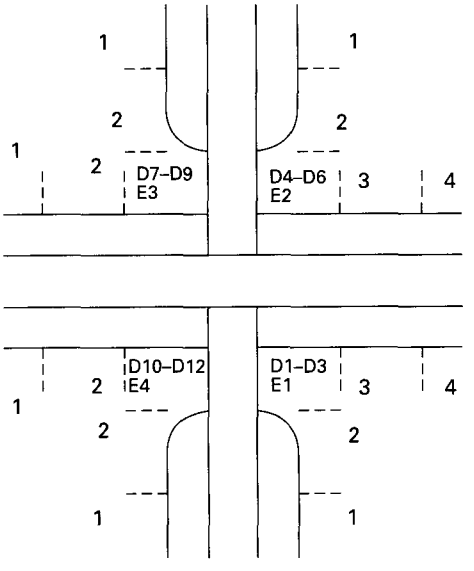

FIG. 10 NOMENCLATURE FOR VERTICAL WELDS

13.9 *Ground-out Areas*

13.9.1 The repair or groundout area is usually 0.5 in. [12.5 mm] wide, and the grind repair probe is designed for the examination of these areas. The probe should be scanned into one end of the groundout area and the scan continued through the other end. Areas with discontinuities should be noted and sized for length and depth with the grind repair probe.

14. Discontinuity Sizing Procedure

14.1 *Length*

14.1.1 Once an area containing a discontinuity has been located, a repeat scan is taken commencing 2 in. [50 mm] before the discontinuity and ending 2 in. [50 mm] after the discontinuity. The B_z length of the discontinuity is determined by locating the extreme ends of the discontinuity using the peak (+ve) and trough (−ve) B_z locations on the X-Y plot. Once these positions are identified they will be marked on the weld toe. It should be noted that these positions should be just inside the actual ends of the discontinuity. Measure the distance between the two points: this is known as the B_z length and is not the actual length of the discontinuity. This value is used in the mathematical model to determine the true length and depth of the discontinuity.

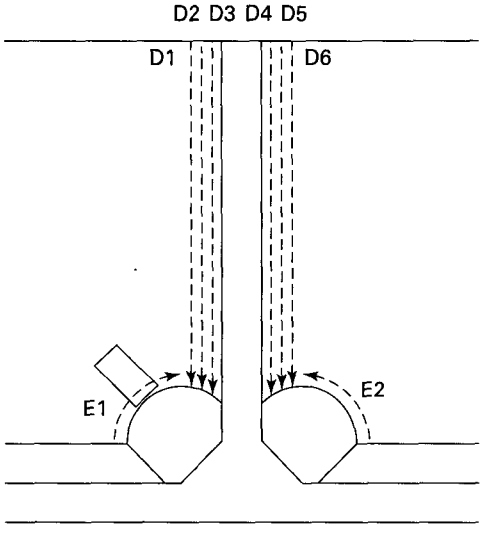

FIG. 11 SCANS OF VERTICAL CUT OUT WELD AND CUT OUT SURFACE

14.2 *Depth*

14.2.1 The depth of the discontinuity is calculated using the B_x minimum and B_x background values and the B_z length of the discontinuity measured from the B_z data. The B_x minimum and B_x background values are determined from the original detection scan. Once these values have been put into the discontinuity depth table, which is part of the mathematical model, together with the B_z length value and coating thickness, if necessary, then the discontinuity depth will be calculated using this mathematical model within the dedicated software.

15. Report

15.1 *Reporting Requirements.* A list of reporting requirements is given in Table 1. Reference should be made to the Client reporting requirements (7.1.14). The items listed below should be included in the examination report. All information below should be archived, whether or not it is required in the report.

15.1.1 Owner, location, type and serial number of component examined.

15.1.2 Size, material type and grade, and configuration of welds examined.

15.1.3 Weld numbering system.

15.1.4 Extent of examination, for example, areas of interest, complete or partial coverage, which welds, and to what length.

15.1.5 The names and qualifications of personnel performing the examination.

TABLE 1
REPORTING REQUIREMENTS

General Information
Date
Operator's Name
Probe Operator
Component ID Number
File Number
Equipment Used
Scanning Data
Filename
Page Number
Position on Weld
Probe Number
Probe Direction
Tape Position
Examination Summary
Detailed Record of Indications/Anomalies
Filename
Page Number
Position on Weld
Start of Discontinuity (Tape reference)
End of Discontinuity (Tape reference)
Length of Discontinuity (in./mm)
Remarks
Diagram/Drawing of component under examination

GENERAL NOTE: The data report sheets generated by the alternating current field measurement examination will be specifically designed with the system and current examination requirements in mind.

15.1.6 Models, types, and serial numbers of the components of the alternating current field measurement system used, including all probes.

15.1.7 For the initial data acquisition from the operation standardization block, a complete list of all relevant instrument settings and parameters used, such as operating frequencies, and probe speed. The list shall enable settings to be referenced to each individual weld examined.

15.1.8 Serial numbers of all of the operations standardization blocks used.

15.1.9 Brief outline of all techniques used during the examination.

15.1.10 A list of all areas not examinable or where limited sensitivity was obtained. Indicate which discontinuities on the operations standardization block would not have been detectable in those regions. Where possible, indicate factors that may have limited sensitivity.

NOTE 1: Factors which influence sensitivity to discontinuities include but are not limited to: operating frequency, instrument noise, instrument filtering, digital sample rate, probe speed, coil configuration, probe travel noise and interference described in Section 8.

15.1.11 Specific information about techniques and depth sizing for each discontinuity.

15.1.12 Acceptance criteria used to evaluate discontinuities.

15.1.13 A list of discontinuities as specified in the purchasing agreement.

15.1.14 Complementary examination results that influenced interpretation and evaluation.

15.2 Record data and system settings in a manner that allows archiving and later recall of all data and system settings for each weld. Throughout the examination, data shall be permanently recorded, unless otherwise specified by the client.

15.2.1 *Report Form.* A typical report form using the dedicated software is shown in Table 2.

16. Keywords

16.1 alternating current field measurement; electromagnetic examination; ferromagnetic weld; non-conducting material; weld

TABLE 2
ALTERNATING CURRENT FIELD MEASUREMENT REPORT FORM

Date: Time:	Location:	Sketch of geometry:
Operator:	Probe Op:	
Component ID:		
Summary of discontinuities:		
Filename:		
Probe Number:		Probe File:

Distance from Datum	Direction of Travel	Weld Position	Page	Examination report/comments

MANDATORY APPENDICES

MANDATORY APPENDIX I
SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL COMMITTEE

A05

I-100 INTRODUCTION

(a) This Appendix provides guidance to Code users for submitting technical inquiries to the Committee. See Guideline on the Approval of New Materials Under the ASME Boiler and Pressure Vessel Code in Section II, Parts C and D for additional requirements for requests involving adding new materials to the Code. Technical inquiries include requests for revisions or additions to the Code rules, requests for Code Cases, and requests for Code interpretations, as described below.

(1) Code Revisions. Code revisions are considered to accommodate technological developments, address administrative requirements, incorporate Code Cases, or to clarify Code intent.

(2) Code Cases. Code Cases represent alternatives or additions to existing Code rules. Code Cases are written as a question and reply, and are usually intended to be incorporated into the Code at a later date. When used, Code Cases prescribe mandatory requirements in the same sense as the text of the Code. However, users are cautioned that not all jurisdictions or owners automatically accept Code Cases. The most common applications for Code Cases are:

(a) to permit early implementation of an approved Code revision based on an urgent need

(b) to permit the use of a new material for Code construction

(c) to gain experience with new materials or alternative rules prior to incorporation directly into the Code

(3) Code Interpretations. Code Interpretations provide clarification of the meaning of existing rules in the Code, and are also presented in question and reply format. Interpretations do not introduce new requirements. In cases where existing Code text does not fully convey the meaning that was intended, and revision of the rules is required to support an interpretation, an Intent Interpretation will be issued and the Code will be revised.

(b) The Code rules, Code Cases, and Code Interpretations established by the Committee are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code rules.

(c) Inquiries that do not comply with the provisions of this Appendix or that do not provide sufficient information for the Committee's full understanding may result in the request being returned to the inquirer with no action.

I-200 INQUIRY FORMAT

Submittals to the Committee shall include:

(a) Purpose. Specify one of the following:

(1) revision of present Code rules

(2) new or additional Code rules

(3) Code Case

(4) Code Interpretation

(b) Background. Provide the information needed for the Committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Division, Edition, Addenda, paragraphs, figures, and tables. Preferably, provide a copy of the specific referenced portions of the Code.

(c) Presentations. The inquirer may desire or be asked to attend a meeting of the Committee to make a formal

presentation or to answer questions from the Committee members with regard to the inquiry. Attendance at a Committee meeting shall be at the expense of the inquirer. The inquirer's attendance or lack of attendance at a meeting shall not be a basis for acceptance or rejection of the inquiry by the Committee.

I-300 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions shall provide the following:

(a) Proposed Revisions or Additions. For revisions, identify the rules of the Code that require revision and submit a copy of the appropriate rules as they appear in the Code, marked up with the proposed revision. For additions, provide the recommended wording referenced to the existing Code rules.

(b) Statement of Need. Provide a brief explanation of the need for the revision or addition.

(c) Background Information. Provide background information to support the revision or addition, including any data or changes in technology that form the basis for the request that will allow the Committee to adequately evaluate the proposed revision or addition. Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraph in the Code that would be affected by the revision or addition and identify paragraphs in the Code that reference the paragraphs that are to be revised or added.

I-400 CODE CASES

Requests for Code Cases shall provide a Statement of Need and Background Information similar to that defined in I-300(b) and I-300(c), respectively, for Code revisions or additions. The urgency of the Code Case (e.g., project underway or imminent, new procedure, etc.) must be defined and it must be confirmed that the request is in connection with equipment that will be ASME stamped, with the exception of Section XI applications. The proposed Code Case should identify the Code Section and Division, and be written as a *Question* and a *Reply* in the same format as existing Code Cases. Requests for Code Cases should also indicate the applicable Code Editions and Addenda to which the proposed Code Case applies.

I-500 CODE INTERPRETATIONS

(a) Requests for Code Interpretations shall provide the following:

(1) Inquiry. Provide a condensed and precise question, omitting superfluous background information and, when possible, composed in such a way that a "yes" or a "no" *Reply,* with brief provisos if needed, is acceptable. The question should be technically and editorially correct.

(2) Reply. Provide a proposed *Reply* that will clearly and concisely answer the *Inquiry* question. Preferably, the *Reply* should be "yes" or "no," with brief provisos if needed.

(3) Background Information. Provide any background information that will assist the Committee in understanding the proposed *Inquiry* and *Reply.*

(b) Requests for Code Interpretations must be limited to an interpretation of a particular requirement in the Code or a Code Case. The Committee cannot consider consulting type requests such as the following:

(1) a review of calculations, design drawings, welding qualifications, or descriptions of equipment or parts to determine compliance with Code requirements;

(2) a request for assistance in performing any Code-prescribed functions relating to, but not limited to, material selection, designs, calculations, fabrication, inspection, pressure testing, or installation;

(3) a request seeking the rationale for Code requirements.

I-600 SUBMITTALS

Submittals to and responses from the Committee shall meet the following:

(a) Submittal. Inquiries from Code users shall be in English and preferably be submitted in typewritten form; however, legible handwritten inquiries will also be considered. They shall include the name, address, telephone number, fax number, and e-mail address, if available, of the inquirer and be mailed to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Three Park Avenue
New York, NY 10016-5990

As an alternative, inquiries may be submitted via e-mail to: SecretaryBPV@asme.org.

(b) Response. The Secretary of the ASME Boiler and Pressure Vessel Committee or of the appropriate Subcommittee shall acknowledge receipt of each properly prepared inquiry and shall provide a written response to the inquirer upon completion of the requested action by the Code Committee.

MANDATORY APPENDIX II
STANDARD UNITS FOR USE IN EQUATIONS

04

TABLE II-1
STANDARD UNITS FOR USE IN EQUATIONS

Quantity	U.S. Customary Units	SI Units
Linear dimensions (e.g., length, height, thickness, radius, diameter)	inches (in.)	millimeters (mm)
Area	square inches ($in.^2$)	square millimeters (mm^2)
Volume	cubic inches ($in.^3$)	cubic millimeters (mm^3)
Section modulus	cubic inches ($in.^3$)	cubic millimeters (mm^3)
Moment of inertia of section	$inches^4$ ($in.^4$)	$millimeters^4$ (mm^4)
Mass (weight)	pounds mass (lbm)	kilograms (kg)
Force (load)	pounds force (lbf)	newtons (N)
Bending moment	inch-pounds (in.-lb)	newton-millimeters (N·mm)
Pressure, stress, stress intensity, and modulus of elasticity	pounds per square inch (psi)	megapascals (MPa)
Energy (e.g., Charpy impact values)	foot-pounds (ft-lb)	joules (J)
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)
Absolute temperature	Rankine (R)	kelvin (K)
Fracture toughness	ksi square root inches ($ksi\sqrt{in.}$)	MPa square root meters ($MPa\sqrt{m}$)
Angle	degrees or radians	degrees or radians
Boiler capacity	Btu/hr	watts (W)

04
A06

NONMANDATORY APPENDIX A
GUIDANCE FOR THE USE OF U.S. CUSTOMARY AND SI UNITS IN THE ASME BOILER AND PRESSURE VESSEL CODE

A-1 USE OF UNITS IN EQUATIONS

The equations in this Nonmandatory Appendix are suitable for use with either the U.S. Customary or the SI units provided in Mandatory Appendix II, or with the units provided in the nomenclature associated with that equation. It is the responsibility of the individual and organization performing the calculations to ensure that appropriate units are used. Either U.S. Customary or SI units may be used as a consistent set. When necessary to convert from one system of units to another, the units shall be converted to at least three significant figures for use in calculations and other aspects of construction.

A-2 GUIDELINES USED TO DEVELOP SI EQUIVALENTS

The following guidelines were used to develop SI equivalents:

(a) SI units are placed in parentheses after the U.S. Customary units in the text.

(b) In general, separate SI tables are provided if interpolation is expected. The table designation (e.g., table number) is the same for both the U.S. Customary and SI tables, with the addition of suffix "M" to the designator for the SI table, if a separate table is provided. In the text, references to a table use only the primary table number (i.e., without the "M"). For some small tables, where interpolation is not required, SI units are placed in parentheses after the U.S. Customary unit.

(c) Separate SI versions of graphical information (charts) are provided, except that if both axes are dimensionless, a single figure (chart) is used.

(d) In most cases, conversions of units in the text were done using hard SI conversion practices, with some soft conversions on a case-by-case basis, as appropriate. This was implemented by rounding the SI values to the number of significant figures of implied precision in the existing U.S. Customary units. For example, 3,000 psi has an implied precision of one significant figure. Therefore, the conversion to SI units would typically be to 20 000 kPa. This is a difference of about 3% from the "exact" or soft conversion of 20 684.27 kPa. However, the precision of the conversion was determined by the Committee on a case-by-case basis. More significant digits were included in the SI equivalent if there was any question. The values of allowable stress in Section II, Part D generally include three significant figures.

(e) Minimum thickness and radius values that are expressed in fractions of an inch were generally converted according to the following table:

Fraction, in.	Proposed SI Conversion, mm	Difference, %
1/32	0.8	−0.8
3/64	1.2	−0.8
1/16	1.5	5.5
3/32	2.5	−5.0
1/8	3	5.5
5/32	4	−0.8
3/16	5	−5.0
7/32	5.5	1.0
1/4	6	5.5
5/16	8	−0.8
3/8	10	−5.0
7/16	11	1.0
1/2	13	−2.4
9/16	14	2.0
5/8	16	−0.8
11/16	17	2.6
3/4	19	0.3
7/8	22	1.0
1	25	1.6

(f) For nominal sizes that are in even increments of inches, even multiples of 25 mm were generally used. Intermediate values were interpolated rather than converting and rounding to the nearest mm. See examples in the following table. [Note that this table does not apply

to nominal pipe sizes (NPS), which are covered below.]

Size, in.	Size, mm
1	25
1⅛	29
1¼	32
1½	38
2	50
2¼	57
2½	64
3	75
3½	89
4	100
4½	114
5	125
6	150
8	200
12	300
18	450
20	500
24	600
36	900
40	1 000
54	1 350
60	1 500
72	1 800

Size or Length, ft	Size or Length, m
3	1
5	1.5
200	60

(g) For nominal pipe sizes, the following relationships were used:

U.S. Customary Practice	SI Practice	U.S. Customary Practice	SI Practice
NPS ⅛	DN 6	NPS 20	DN 500
NPS ¼	DN 8	NPS 22	DN 550
NPS ⅜	DN 10	NPS 24	DN 600
NPS ½	DN 15	NPS 26	DN 650
NPS ¾	DN 20	NPS 28	DN 700
NPS 1	DN 25	NPS 30	DN 750
NPS 1¼	DN 32	NPS 32	DN 800
NPS 1½	DN 40	NPS 34	DN 850
NPS 2	DN 50	NPS 36	DN 900
NPS 2½	DN 65	NPS 38	DN 950
NPS 3	DN 80	NPS 40	DN 1000
NPS 3½	DN 90	NPS 42	DN 1050
NPS 4	DN 100	NPS 44	DN 1100
NPS 5	DN 125	NPS 46	DN 1150
NPS 6	DN 150	NPS 48	DN 1200
NPS 8	DN 200	NPS 50	DN 1250
NPS 10	DN 250	NPS 52	DN 1300
NPS 12	DN 300	NPS 54	DN 1350
NPS 14	DN 350	NPS 56	DN 1400
NPS 16	DN 400	NPS 58	DN 1450
NPS 18	DN 450	NPS 60	DN 1500

(h) Areas in square inches ($in.^2$) were converted to square mm (mm^2) and areas in square feet (ft^2) were converted to square meters (m^2). See examples in the following table:

Area (U.S. Customary)	Area (SI)
1 $in.^2$	650 mm^2
6 $in.^2$	4 000 mm^2
10 $in.^2$	6 500 mm^2
5 ft^2	0.5 m^2

(i) Volumes in cubic inches ($in.^3$) were converted to cubic mm (mm^3) and volumes in cubic feet (ft^3) were converted to cubic meters (m^3). See examples in the following table:

Volume (U.S. Customary)	Volume (SI)
1 $in.^3$	16 000 mm^3
6 $in.^3$	100 000 mm^3
10 $in.^3$	160 000 mm^3
5 ft^3	0.14 m^3

(j) Although the pressure should always be in MPa for calculations, there are cases where other units are used in the text. For example, kPa is used for small pressures. Also, rounding was to one significant figure (two at the most) in most cases. See examples in the following table. (Note that 14.7 psi converts to 101 kPa, while 15 psi converts to 100 kPa. While this may seem at first glance to be an anomaly, it is consistent with the rounding philosophy.)

Pressure (U.S. Customary)	Pressure (SI)
0.5 psi	3 kPa
2 psi	15 kPa
3 psi	20 kPa
10 psi	70 kPa
14.7 psi	101 kPa
15 psi	100 kPa
30 psi	200 kPa
50 psi	350 kPa
100 psi	700 kPa
150 psi	1 MPa
200 psi	1.5 MPa
250 psi	1.7 MPa
300 psi	2 MPa
350 psi	2.5 MPa
400 psi	3 MPa
500 psi	3.5 MPa
600 psi	4 MPa
1,200 psi	8 MPa
1,500 psi	10 MPa

(k) Material properties that are expressed in psi or ksi (e.g., allowable stress, yield and tensile strength, elastic modulus) were generally converted to MPa to three significant figures. See example in the following table:

Strength (U.S. Customary)	Strength (SI)
95,000 psi	655 MPa

(l) In most cases, temperatures (e.g., for PWHT) were

rounded to the nearest 5°C. Depending on the implied precision of the temperature, some were rounded to the nearest 1°C or 10°C or even 25°C. Temperatures colder than 0°F (negative values) were generally rounded to the nearest 1°C. The examples in the table below were created by rounding to the nearest 5°C, with one exception:

Temperature, °F	Temperature, °C
70	20
100	38
120	50
150	65
200	95
250	120
300	150
350	175
400	205
450	230
500	260
550	290
600	315
650	345
700	370
750	400
800	425
850	455
900	480
925	495
950	510
1,000	540
1,050	565
1,100	595
1,150	620
1,200	650
1,250	675
1,800	980
1,900	1 040
2,000	1 095
2,050	1 120

A-3 SOFT CONVERSION FACTORS

The following table of "soft" conversion factors is provided for convenience. Multiply the U.S. Customary value by the factor given to obtain the SI value. Similarly, divide the SI value by the factor given to obtain the U.S. Customary value. In most cases it is appropriate to round the answer to three significant figures.

U.S. Customary	SI	Factor	Notes
in.	mm	25.4	...
ft	m	0.3048	...
$in.^2$	mm^2	645.16	...
ft^2	m^2	0.09290304	...
$in.^3$	mm^3	16,387.064	...
ft^3	m^3	0.02831685	...
U.S. gal	m^3	0.003785412	...
U.S. gal	liters	3.785412	...
psi	MPa (N/mm^2)	0.0068948	Used exclusively in equations
psi	kPa	6.894757	Used only in text and for nameplate
psi	bar	0.06894757	...
ft-lb	J	1.355818	...
°F	°C	$\frac{5}{9} \times (°F - 32)$	Not for temperature difference
°F	°C	$\frac{5}{9}$	For temperature differences only
R	K	$\frac{5}{9}$	Absolute temperature
lbm	kg	0.4535924	...
lbf	N	4.448222	...
in.-lb	N·mm	112.98484	Use exclusively in equations
ft-lb	N·m	1.3558181	Use only in text
$ksi\sqrt{in.}$	$MPa\sqrt{m}$	1.0988434	...
Btu/hr	W	0.2930711	Use for boiler rating and heat transfer
lb/ft^3	kg/m^3	16.018463	...

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ASME Boiler and Pressure Vessel Code
SECTION V

INTERPRETATIONS
Volume 54

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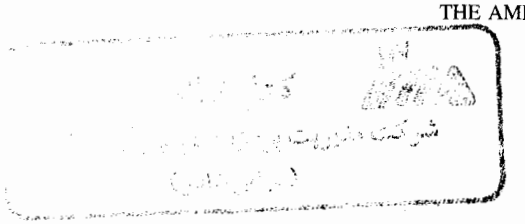

INTERPRETATIONS
VOLUME 54 — SECTION V

Replies to Technical Inquiries
July 1, 2003 through December 31, 2003

FOREWORD

This publication includes all written interpretations issued between the indicated dates by the ASME Staff on behalf of the ASME Boiler and Pressure Vessel Committee in response to inquiries concerning interpretations of the ASME Boiler and Pressure Vessel Code. A contents is also included which lists subjects specific to the interpretations covered in the individual volume.

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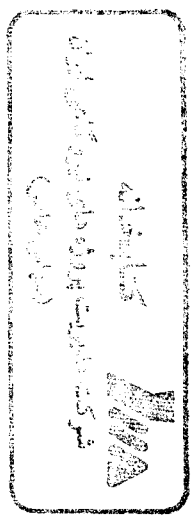
SECTION V

Subject	Interpretation	File No.
Section V, Article 2, Para. T-274, Geometric Unsharpness	V-04-03	BC02-3627
Section V, Article 2, Paras. T-277, T-282, and T-283	V-04-01	BC03-1351
Section V, Intent Interpretation, Article 2, Para. T-291	V-04-05	BC02-2362
Section V, Article 5	V-04-02	BC03-1352
Section V, Article 6, Para. T-676.3	V-04-04	BC03-1659



Interpretation: V-04-01

Subject: Section V, Article 2, Paras. T-277, T-282, and T-283 (2001 Edition, 2002 Addenda)

Date Issued: October 2, 2003

File: BC03-1351

Question: In radiographing a weld seam on a 2-to-1 ellipsoidal head or a longitudinal weld seam with multiple film holders (4 or more) in a single exposure, an IQI image is projected on the middle film holder and on each end film holder. When the requirements of T-282 and T-283 are met, will any additional IQIs be needed to meet the requirements of para. T-277?

Reply: Yes.

Interpretation: V-04-02

Subject: Section V, Article 5 (2001 Edition, 2002 Addenda)

Date Issued: October 2, 2003

File: BC03-1352

Question (1): Does the requirement of para. T-531 for the reject control to be in the "off" position for all examinations unless it can be demonstrated that it does not affect the linearity of the examination, apply when examining tubular product using an automated "accept/reject" system?

Reply (1): Yes.

Question (2): Is the linearity check frequency as required in Section V, Article 5, para. T-561 (2001 Edition, 2002 Addenda) the same frequency as required in Section V, Article 5, paras. T-532 and T-533 (2001 Edition)?

Reply (2): Yes.

Question (3): Do the requirements of Section V, Article 5, para. T-563.3.1 (2001 Edition, 2002 Addenda) apply when using an automatic "accept/reject" examination system?

Reply (3): Yes.

Question (4): Do the requirements of Section V, Article 5, para. T-563.3.2 (2001 Edition, 2002 Addenda) apply to all product forms using manual or automatic systems?

Reply (4): Yes.

Question (5): May the words "shall be re-examined" in Section V, Article 5, para. T-563.3.2 (2001 Edition, 2002 Addenda) be interpreted to mean "can be re-examined"?

Reply (5): No.

Interpretation: V-04-03

Subject: Section V, Article 2, Para. T-274, Geometric Unsharpness (2001 Edition)

Date Issued: October 9, 2003

File: BC02-3627

Question: When calculating U_g (geometric unsharpness) in accordance with ASME Section V, Article 2, para. T-274 (2001 Edition), is it permissible to use the length of the source (source size-F) as the projected dimension perpendicular to the distance D (distance from the weld or object being radiographed, in.) when the source length is placed perpendicular to the distance D?

Reply: No.

Interpretation: V-04-04

Subject: Section V, Article 6, Para. T-676.3 (2001 Edition, 2003 Addenda)

Date Issued: December 17, 2003

File: BC03-1659

Question (1): Is it required that the light intensity from a demonstrated light source at the surface to be examined be measured with a light meter during each examination and evaluation of indications to assure a minimum light intensity of 100 fc?

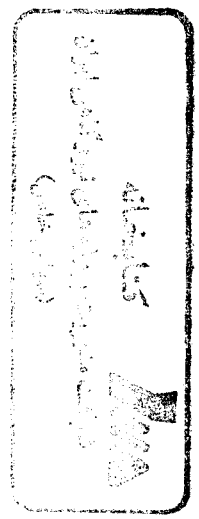
Reply (1): No.

Question (2): During the one-time documented demonstration and verification of the light source and the technique used, is it required that the light level (intensity) at the surface to be examined be measured with a light meter?

Reply (2): Yes.

Question (3): Does calculation through geometry of the light level at the surface to be examined using information provided by the light source manufacturer regarding the amount of light produced by the source satisfy the requirement to verify the light level during demonstration of the technique and light source?

Reply (3): No.



Interpretation: V-04-05

Subject: Section V, Intent Interpretation; Article 2, Para. T-291 (2001 Edition)

Date Issued: December 17, 2003

File: BC02-2362

Question: Is it the intent of ASME Section V, Article 2, paras. T-291(g) and T-291(h) to determine the "minimum source-to-object distance" and the "distance from source side of object to film" (d in T-274.1) at a single center point, which is perpendicular to the radiation source?

Reply: Yes.

ASME Boiler and Pressure Vessel Code
SECTION V

INTERPRETATIONS
Volume 55

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INTERPRETATIONS
VOLUME 55 — SECTION V

Replies to Technical Inquiries
January 1, 2004 through December 31, 2004

FOREWORD

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SECTION V

Subject	Interpretation	File No.
Section V, Article 2, T-282.2(b)	V-04-06	BC04-305
Section V, Article 5	V-04-08	BC04-133
Section V, Article 6, T-660, Light Meters	V-04-07	BC04-306

Interpretation: V-04-06

Subject: Section V (2001 Edition, 2003 Addenda), Article 2, T-282.2(b)

Date Issued: March 22, 2004

File: BC04-305

Question (1): Does the maximum density limit of 4.0 in T-282.1 apply to radiographic images produced with shimmed hole-type IQIs?

Reply (1): Yes.

Question (2): May a radiographic image produced with a shimmed hole-type IQI meet the requirements of T-282.2(b) with a density reading up to 4.0 through the IQI image, if the sensitivity requirements of T-283.1 are satisfied and the density reading through the area of interest meets the requirement of T-282.1?

Reply (2): Yes.

Interpretation: V-04-07

Subject: Section V (2001 Edition, 2003 Addenda), Article 6, T-660, Light Meters

Date Issued: April 1, 2004

File: BC04-306

Question: Except when the visible lighting technique has been previously documented as acceptable, must an examiner performing visible or fluorescent liquid penetrant examinations in compliance with Article 6 have a calibrated light meter available to determine the acceptability of available lighting per the requirements of T-676.3 and T-676.4?

Reply: Yes.

Interpretation: V-04-08

Subject: Section V (1998 Edition), Article 5

Date Issued: October 26, 2004

File: BC04-133

Question (1): With respect to Article 5, T-542.3.4, may a flat calibration block be used for calibration when examining welds in ferritic pipe where examination surface diameter is greater than 20 in. (500 mm)?

Reply (1): Yes.

Question (2): With respect to Article 5, T-542.8.2.4, may a calibration block with side-drilled holes be used for calibration when examining ferritic welds in ferritic pipe if it has been demonstrated that the hole calibration produces a sensitivity equal to or greater than both the circumferential and axial notch calibrations?

Reply (2): Yes.

Question (3): With respect to Article 5, T-542.8.1.2, footnote 1, when a calibration block with side-drilled holes is used in lieu of a calibration block with notches for calibration when examining ferritic welds in ferritic pipe, must the hole locations comply with Fig. T-542.2.1?

Reply (3): Yes.

ASME Boiler and Pressure Vessel Code
SECTION V

INTERPRETATIONS
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INTERPRETATIONS
VOLUME 56 — SECTION V

Replies to Technical Inquiries
January 1, 2005 through December 31, 2005

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SECTION V

Subject	Interpretation	File No.
Section V, Article 2, T-271	V-04-11	BC05-1057
Section V, Article 2, T-276.2(a)	V-04-10	BC04-1497
Section V, Article 5, T-542.3.4	V-04-12	BC05-1424
Section V, Article 7, T-741.2 and Table T-721	V-04-09	BC04-1080

Interpretation: V-04-09

Subject: Section V (2001 Edition, 2003 Addenda), Article 7, T-741.2 and Table T-721

Date Issued: June 29, 2005

File: BC04-1080

Question (1): Is it the intent of Article 7, T-741.2 that nonmagnetic surface contrast enhancement be considered a coating as addressed in Table T-721?

Reply (1): No.

Question (2): Is it the intent of T-741.2 and Table T-721 that nonmagnetic surface contrast enhancement be considered an essential variable for magnetic particle examination?

Reply (2): Yes.

Interpretation: V-04-10

Subject: Section V (2001 Edition), Article 2, T-276.2(a)

Date Issued: July 26, 2005

BC04-1497

Question: Is it permitted to base the IQI selection on the nominal single-wall thickness plus up to the maximum weld reinforcement permitted by the referencing Code Section?

Reply: Yes, provided the weld reinforcement has been estimated to be the maximum permitted by the referencing Code Section.

Interpretation: V-04-11

Subject: Section V (2004 Edition), Article 2, T-271

Date Issued: October 18, 2005

File: BC05-1057

Question (1): In accordance with Article 2, T-271.2(b)(1) or T-271.2(b)(2), is full radiographic coverage obtained by viewing both the near-side and far-side walls and the two side-wall areas with a single exposure of a small diameter ($3\frac{1}{2}$ in. or less) tube butt weld, as shown in Article 2, Nonmandatory Appendix A, Exposure Arrangements "F" or "G"?

Reply (1): No.

Question (2): Does Article 2, T-271.2(b)(1) or T-271.2(b)(2), require the side-wall areas of a small diameter ($3\frac{1}{2}$ in. or less) tube butt weld to be visible on a radiograph when using a double wall exposure, double wall viewing technique as shown in Article 2, Nonmandatory Appendix A, Exposure Arrangements "F" or "G"?

Reply (2): No.

Interpretation: V-04-12

Subject: Section V (1998 Edition), Article 5, T-542.3.4

Date Issued: October 26, 2005

File: BC05-1424

Question: With respect to Article 5, T-542.3.4, may a flat calibration block be used for calibration when examining welds in ferritic pipe where examination surface diameter is equal to or less than 20 in. (500 mm)?

Reply: No.